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Evaluation of Troposcatter Propagation in Iceland

By

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Troposcatter radio links are being considered as a possible way to satisfy some communication needs of the Iceland Air Defense System. This report documents a test program conducted during September and October of 1986 to determine the performance level of digital troposcatter in the Iceland climate. Major emphasis was placed on comparing measurements of path loss and multipath delay spread with predicted values. This comparison was necessary because the models are empirical and contain no data for extreme northern latitudes. The results of these measurements and the ensuing model adjustments are presented. The primary conclusion is that higher system gain than predicted at C-band is required to support troposcatter links in Iceland.

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EXECUTIVE SUMMARY

The Iceland Air Defense System (IADS) is a NATO-funded program to upgrade the surveillance, data processing, and communication segments of the Iceland Air Defense Ground Environment. One possible means of providing communications between IADS radar sites is digital troposcatter radio links.

The results of a preliminary site survey and assessment revealed a number of feasible links. However, the link margins were small, and the prediction model used was empirical and contained no data for extreme northern latitudes. To reduce the risks associated with establishing new links, a 30-day link evaluation was proposed in June 1986 and conducted during September and October of 1986.

The primary objective of the link evaluation was to determine the accuracy of the prediction programs for the Iceland climate. If the models were found to be inaccurate, the necessary model adjustments would be derived from the collected data. In either case, planning for troposcatter links in Iceland could then be performed with more confidence.

For adaptive digital radios, knowledge of both path loss and multipath delay spread are needed to estimate link performance. Both of these parameters were measured on a test link between Vik and Keflavik, Iceland, using AN/TRC-170 digital radios and the Automated Experiment Measurement System (AEMS). In addition, 2 years of path loss data from the existing Hofn-Dye 5 Iceland link were obtained and

analyzed. The TRC-170 radio operates at C-band frequencies while the analog Hofn-Dye 5 link operates at L-band. The Signatron "TROPO" prediction program and MITRE's adaptation of it, called Site Analysis Tools (SAT), were used to estimate the performance of both links.

The observed multipath delay spread (MDS) was slightly less than, but still in good agreement with, the SAT the prediction and within the performance range of existing adaptive digital modems. The path loss observed at both C-band and L-band was larger than predicted. Using both the AN/TRC-170 data and the two years of Hofn-Dye 5 data, adjustments to the path loss model were determined. The adjustments were baselined to the predicted 0.50 confidence, 0.99 availability value. For 0.50 confidence, 4.4 dB should be added, and for 0.90 confidence, 12.0 dB should be added.

The result of this analysis is that C-band radio links, when used in Iceland, require higher system gain than originally predicted. Both the L-band and C-band data indicate that new median adjustment factors and variability functions for the Iceland latitudes should be created.

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The Iceland test program was conducted on short notice and could not have been performed successfully without the cooperation and enthusiasm of several organizations and individuals. Dr. Palsson, of the University of Iceland, and Government of Iceland representatives provided the resources for site surveys and site selection. Lt. Col. Gaetz and Lt. Villarreal of the American Forces, Iceland, provided outstanding support in both the planning and conducting of the test. Thanks also to Maj. Adams, the Air Force Test Team and Raytheon, all at Fort Huachuca, for getting the TRC-170 radios and AEMS airlifted to Iceland and for 24-hour support of the test sites. A special thanks to Messrs. Honea and Wasilewski of MITRE for providing technical site support. Also appreciated is the cooperation of Messrs, Teague, Currell, and Faulk at Dye 5 in providing data for the Hofn-Dye 5 link. A warm and special thanks to Ms. Warren for typing and retyping this document. Her patience with constant rewrites was appreciated.

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SECTION 1

INTRODUCTION

A test program was conducted during September and October of 1986 to determine the performance level of digital troposcatter radio links in the Iceland climate. Major emphasis was placed on comparing measurements of path loss and multipath delay spread with predicted values. This comparison was necessary because the models used, and all other known models, are empirical and contain no data for extreme northern latitudes.

The purpose of the test program was to determine what, if any, adjustments to the models were required to accurately predict digital troposcatter performance in Iceland. The adjusted or verified models could then be used with higher confidence in making troposcatter predictions. Although not a part of this study, the results of this analysis could be applied to other parts of the world with similar climatology.

Data from two troposcatter links in Iceland, shown in figure 1-1, were analyzed. The first was an existing 800 MHz link from Hofn to Dye 5, operating since the early 1960s. The second link, from Vik to Keflavik, was temporarily installed specifically for this test program.

This report documents the analysis of data on the two links and presents initial model adjustments for the Iceland climate.

1.1 BACKGROUND

The test program was conducted in support of the Iceland Air Defense System (IADS) program. IADS is a NATO-funded program to

Figure 1-1. Iceland Links

upgrade the surveillance, data processing, and communications segments of the Iceland Air Defense Ground Environment. A portion of this program involves the selection and implementation of multichannel communications among various sites. One possible means of providing these communications is via digital troposcatter radio links.

A preliminary assessment of digital troposcatter radio links was conducted in June 1986. The results of this assessment revealed that a number of the proposed links were feasible; however, link margins were small, and the prediction models used were not based on data from latitudes representative of Iceland. Therefore, the effort reported in this paper was conducted.

1.2 TEST OBJECTIVES

The primary objective of the Iceland troposcatter propagation effort was to determine the accuracy of the prediction programs for the Iceland climate. If the models were found to be inaccurate, the necessary model adjustments would be derived from the collected data. In either case, planning for troposcatter links in Iceland could then be performed with more confidence.

1.3 TEST PARTICIPANTS

The test program was developed to evaluate propagation and performance on the Vik-Keflavik link in the September-October 1986 test period and to analyze existing data from the Hofn to Dye 5 link. The effort was conducted in a cooperative manner with the agencies and organizations listed below:

Organization	Basic Responsibility
AFI	Military host/operational organization
ESD/SCB	Program sponsor and test direction
ESD/TCJ-2 Hanscom AFB, MA	AN/TRC-170 system acquisition
ESD/TCJT Ft. Huachuca, AZ	AN/TRC-170 system & Automated Experiment Measurement System (AEMS) operation

The MITRE Corp., Ft. Huachuca, AZ	AEMS data facility, test link selection, troubleshooting, data acquisition, analysis, and test report
Raytheon Corp., (Under ESD Contract)	Contractual maintenance and installation of AN/TRC-170

1.4 DESCRIPTION OF REPORT

Section 2 details the link parameters, data acquisition method, and measurement parameters for both the existing Hofn-Dye 5 800 MHz link and the 5 GHz Vik-Keflavik test link. A brief background of the propagation models used to predict performance of the two links and the actual predictions are presented in section 3. Section 4 analyzes the results of the collected data to determine how well the predictions agree with the actual measurements. The impact of these results and the recommended adjustments to the prediction model for path loss for the Iceland climate are discussed in section 5. A brief introduction to digital tropo modems and their dependence on multipath delay spread is presented in appendix A. Finally, the detailed AEMS data for the entire test is presented in appendix B.

SECTION 2

MEASUREMENT PROGRAM DESCRIPTION

This section details the link parameters, data acquisition method, and measurement parameters for both the existing Hofn-Dye 5 800 MHz link and the 5 GHz Vik-Keflavik test link. In addition, a path profile for the Vik-Keflavik link and pictures of both sites are presented.

2.1 HOFN-DYE 5 LINK

The Hofn-Dye 5 troposcatter link is a 377 km link operating at 800 MHz traversing the southern part of Iceland (see figure 1-1). This link has been in operation since 1960 and is part of the North Atlantic Radio System (NARS). This link was an important part of the program because time and funding restricted testing to only one 5 GHz link (Vik-Keflavik).

Historical once-a-day received signal level (RSL) data for past years was available. This data was used to define the relationship between the 5 GHz data (September-October Vik-Keflavik) and data from other September-October time periods, thereby improving the confidence level of any model adjustments. Table 2.1 details the link parameters for the Hofn-Dye 5 link.

2.1.1 Data Acquisition Method

Personnel at the Dye 5 site maintain daily records of RSL. The readings are taken on each of the four receivers at the intermediate frequency (IF) at approximately 4 a.m. local time each day using a spectrum analyzer. Data for 2 complete years were obtained. The

Table 2.1. Hofn to Dye 5 Link Parameters

Parameters	Transmit (Hofn)	Receive (Dye 5)
Coordinates	$64^{\circ}14'32''$ N $14^{\circ}58'46''$ W	$63^{\circ}57'27''$ N $22^{\circ}43'8''$ W
Site Elevation (MSL)	24 ft (7.3 m)	27 ft (8.2 m)
Antenna Diameter	120 ft (36.58 m)	120 ft (36.58 m)
Antenna Heights	74 ft (22.6 m)	74 ft (22.6 m)
Antenna Spacing (horizontal)	150 ft (45.72 m)	150 ft (45.72 m)
Horizon Angle	1.08°	0.31°
Horizon Distance	36.0 sm (58 km)	34.2 sm (55 km)
Horizon Elevation	4331 ft (1320 m)	1647 ft (502 m)
Nominal Transmit Power	40 kW	
Antenna Gains	47.7 dB	47.7 dB
System Losses	1.2 dB	1.2 dB
Foreground	smooth bay, irregular horizon	long valley, irregular horizon

Diversity	Quad (space/frequency)
Path length	234 sm (377 km)
Frequency	0.800 GHz
Channels	120, 4 kHz channels
Operation Interval	Since 1960
Surface Refractivity	320

first year consisted of the 12 months of 1982, and the second year consisted of a continuous 12-month period spanning both 1985 and 1986. In addition, during the September-October 1986 test period, Dye 5 personnel collected data every 6 hours.

2.1.2 Measurement Parameters

The path loss was determined from the RSL and the known equipment parameters from table 2.1 using the following equation:

$$PL = P_{TX} + G_T + G_R - RSL - L_E + M_T$$

where:

P_{TX} = Transmit Power (76 dBm)
G_T = Transmit Antenna Gain (47.7 dB)
G_R = Receive Antenna Gain (47.7 dB)
RSL = Receive Signal Level (dBm)
L_E = Equipment Losses (2.4 dB)
M_T = Measurement Technique Adjustment (4 dB)

All parameters with the exception of RSL were assumed to be constant and included gains and losses not accounted for in the RSL calibration. The resulting path loss provided a measure of path performance independent of system parameters and included two terms, propagation loss and antenna aperture-to-medium coupling loss.

M_T corrects for the measurement methods employed. First, in a calibration test performed at the Dye 5 site, RSL spectrum analyzer readings were 1 dB less than power meter readings when measuring the steady state composite IF signal. Therefore, actual path losses were 1 dB less than recorded. RSL readings tended to be peaks of

generally slow fading signals, according to Dye 5 personnel. Prediction programs employ a median value rather than a peak value. The rationale for adjusting the peak readings to median values is as follows.

Assuming this 800 MHz, narrowband radio link has Rayleigh fading statistics over a period of a minute or less, the median is proportional to the peak value. Table 2.2 shows the parameters of interest for a Rayleigh distribution function. By observing the signal over many fades, the peak value, or the value closest to the peak value, should be recorded. Then, during the observation period, successive peaks will be easy to see, but fades will be limited by the system noise floor. Thus, the Rayleigh fading will appear over some limited range. If it is assumed that 99.9 percent of the distribution is observed (a reasonable assumption), then the peak-to-median adjustment is -5 dB. Even if this assumption is not exactly correct, the adjustment should be within 1 dB. Thus, the net M_T is 4 dB (-5 dB + 1 dB).

Table 2.2. Parameters for a Rayleigh Distribution

Variate	Offset From Peak to Variate	Peak-to-Median Ratio (dB)
Peak	0	
Mean	σ	
Median	1.177σ	
99 percentile	3.0σ	-4.1
99.9 percentile	3.7σ	-5.0
99.99 percentile	4.3σ	-5.6

2.2 VIK-KEFLAVIK LINK

The Vik-Keflavik link was selected as the test link for the following reasons:

a. The Keflavik site was on the agreed area at the Keflavik base, making access easy.

b. The Vik site was an Iceland public telephone system site, making government approval less complicated.

c. The link was representative of the proposed links, i.e., relatively high takeoff angles with a portion of the link traversing water.

d. The link length of 191 km matched the TRC-170(V2) radio capabilities with an acceptable margin for propagation unknowns.

2.2.1 Link Parameters

Table 2.3 details the parameters for this link and figure 2-1 details the path profile. At the Keflavik site, the foreground slopes downward for the first kilometer and then gradually upward to the horizon which is 23 kilometers from the site. Figure 2-2 shows the foreground of the Keflavik site; note the arrow showing the approximate location of the radio horizon. Figure 2-3 is a picture of the Keflavik site. It shows the TRC-170(V2) radio, two 2.9 meter antennas, the AEMS, and a third shelter serving as a site office.

The foreground at the Vik site drops from 300 meters to 70 meters in 1.5 kilometers. For the next 40 kilometers, the foreground

Table 2.3. Vik to Keflavik Link Parameters

Parameters	Transmit (Vik)	Receive (Keflavik)
Coordinates	63°26'32" N 18°52'12" W	63°58'30" N 22°33'40" W
Site Elevation (MSL)	965 ft (294 m)	148 ft (45 m)
Antenna Diameter	9.5 ft (2.90 m)	9.5 ft (2.90 m)
Antenna Heights	15 ft (4.57 m)	15 ft (4.57 m)
Antenna Spacing (horizontal)	26 ft (7.92 m)	26 ft (7.92 m)
Horizon Angle	0.47°	0.61°
Horizon Distance	24 sm (38.2 km)	14 sm (22.6 km)
Horizon Elevation	2297 ft (700 m)	1050 ft (320 m)
Nominal Transmit Power	1.6 kW	
Antenna Gains	40 dB	40 dB
System Instrumentation Losses	0.5 dB	0.5 dB
Foreground	valley, irregular horizon	valley, irregular horizon

Diversity	Quad (space/frequency)
Path length	119 miles (191 km)
Frequency	4.884 GHz
Bandwidth	3.5 MHz
Mission Rate	256 to 512 kb/s
RAKE Probe BW	10 MHz
Surface Refractivity	320

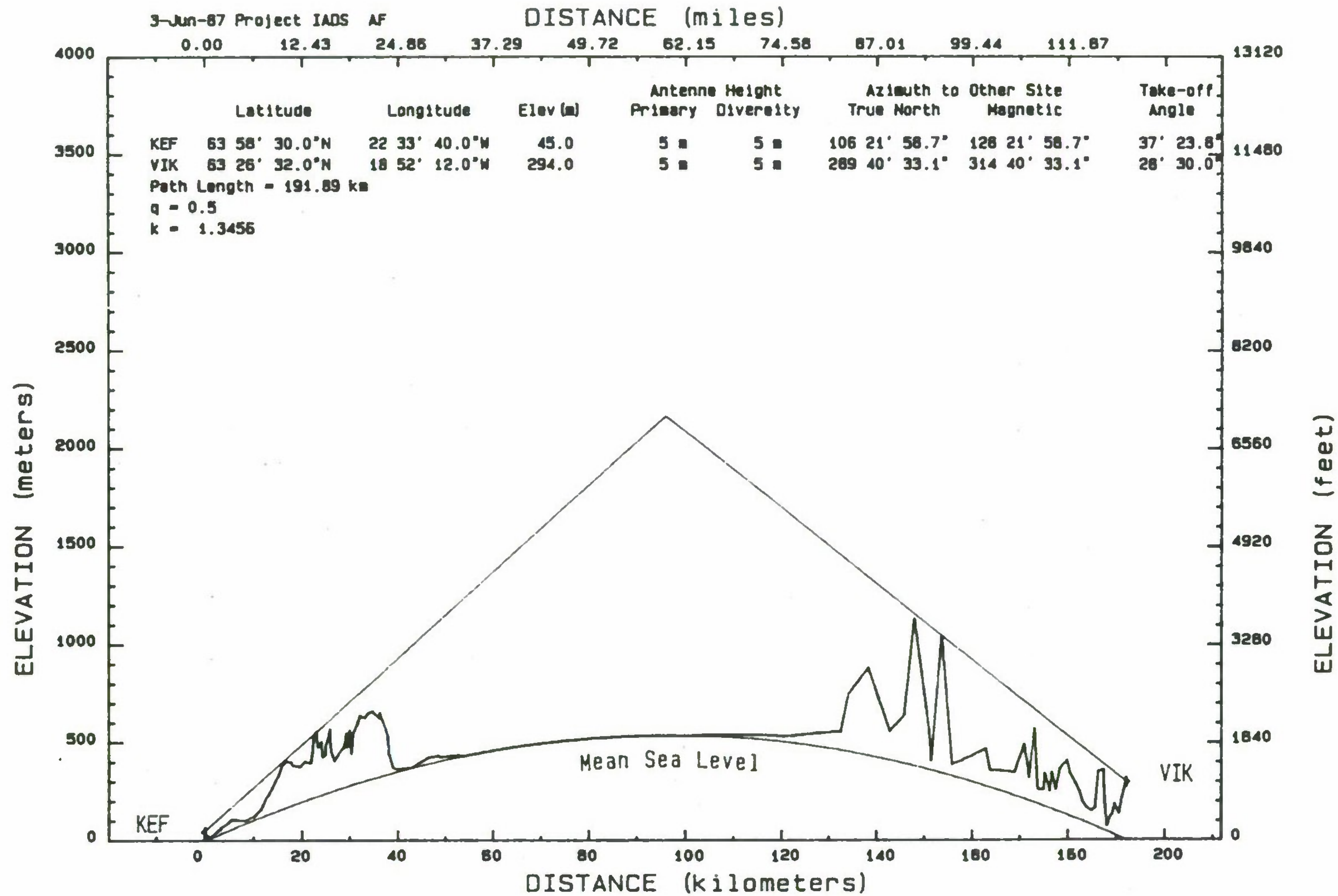


Figure 2-1. Path Profile From Vik to Keflavik

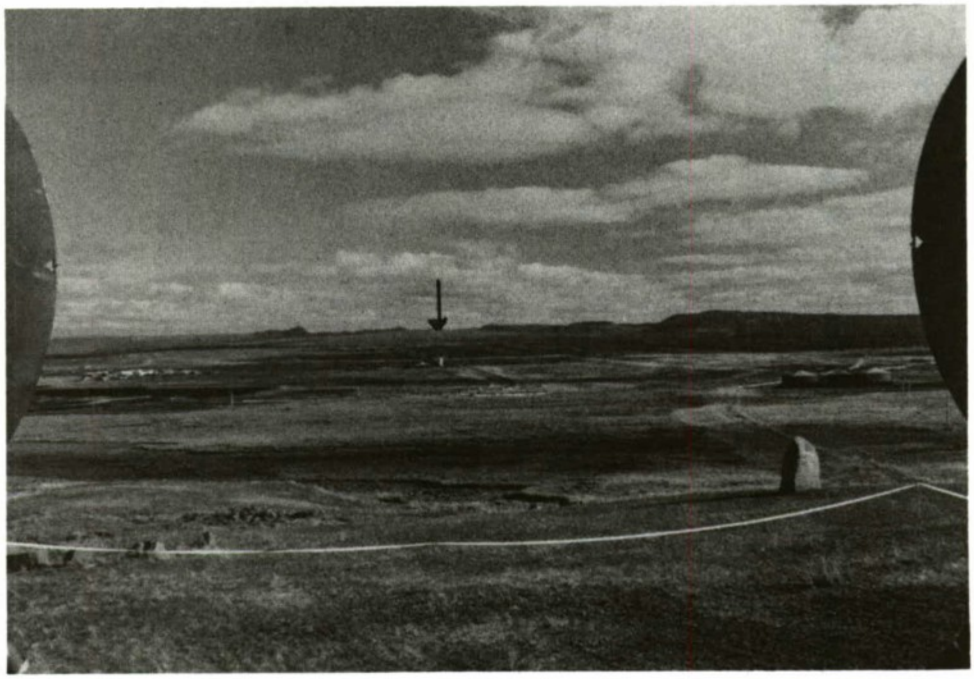


Figure 2-2. Keflavik Foreground

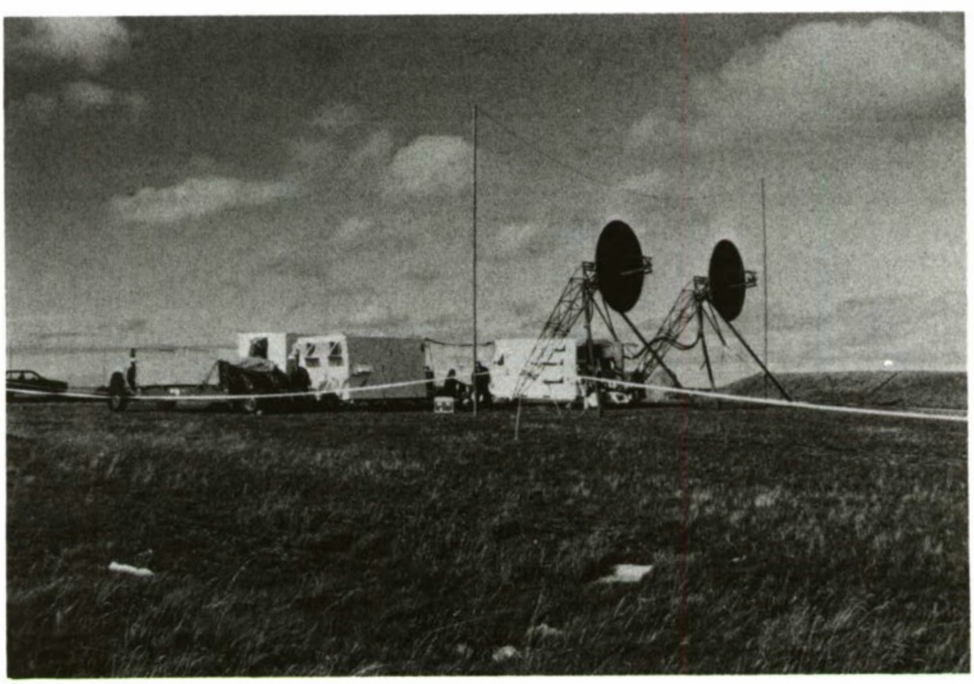


Figure 2-3. Keflavik Test Site

is very cluttered with mountainous terrain. The radio horizon is 38 kilometers from the site at an elevation of 700 meters. Figure 2-4 shows the foreground at the Vik site with the arrow denoting the approximate location of the radio horizon.

2.2.2 Data Acquisition Method

The AN/TRC-170(V2) Digital Troposcatter Radios with 2.9-meter parabolic antennas, currently used in the test program at Fort Huachuca, AZ, served as host radios for the test. Personnel from the Air Force Tactical Communications Office (ESD/MITRE) at Fort Huachuca directed the placement, installation, and operation of the radio system.

Path propagation and link performance data were acquired using the AEMS facility. The AEMS is a data acquisition and processing system designed by ESD/MITRE for use in the AN/TRC-170 test program. It is housed in an S-280 shelter, is based on a PDP-11 computer system, and includes the interface equipment to the AN/TRC-170 radio. A system block diagram of the AEMS data-collection system and its interfaces with the AN/TRC-170 radio are shown in figure 2-5. The configurations used during this test are discussed in section 2.2.3, and the detailed measurement capabilities in section 2.2.4.

2.2.3 Test Configurations

To satisfy the objectives of this test program, certain measurement parameters were defined as minimum requirements. These parameters are the same ones used throughout the TRC-170 link engineering program sponsored by the USAF. The link was operated for

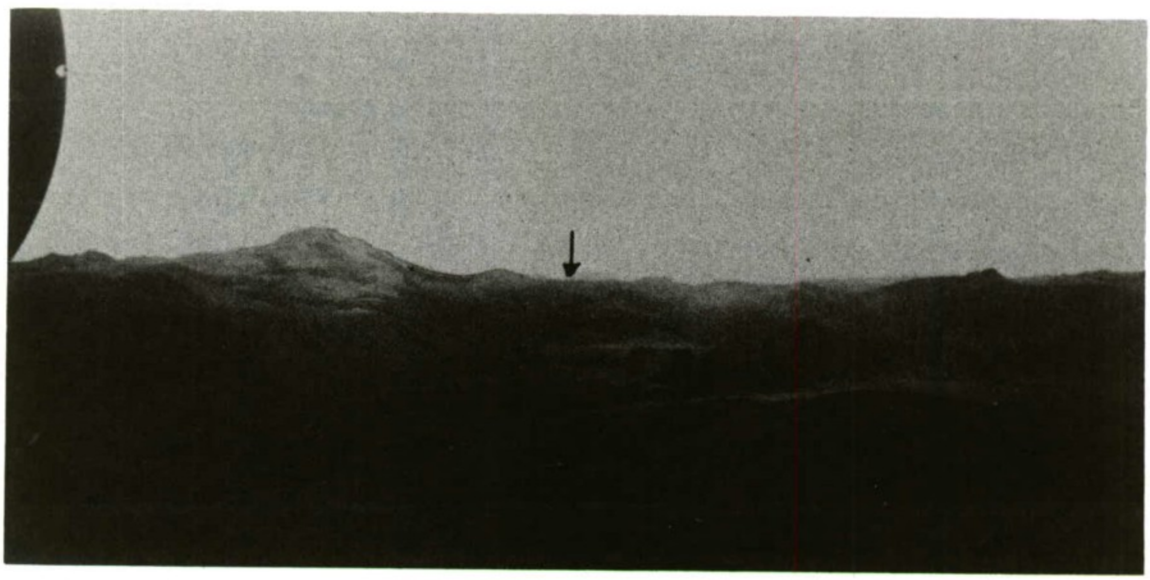


Figure 2-4. Foreground at Vik

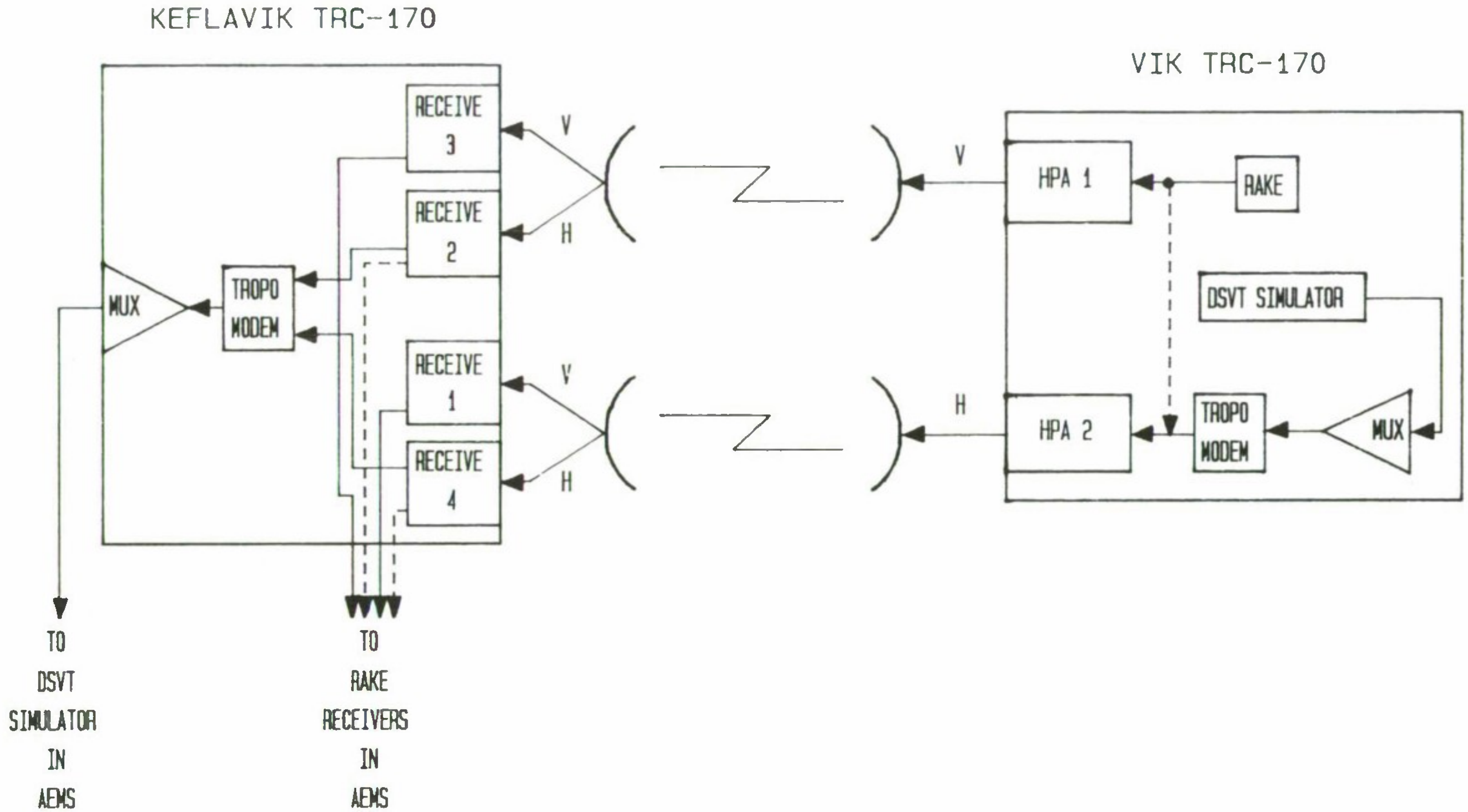


Figure 2-5. AEMS to TRC-170 Interfaces

4 weeks, 5 days a week, 24 hours a day. Three different test configurations were used to probe the test link. A description of each is provided in the following subsections.

2.2.3.1 Dual RAKE, Dual Bit Error Rate

This basic data acquisition configuration is referred to as "BERK." It is depicted by the solid lines in figure 2-6. In this mode, dual diversity bit error rate (BER) data is collected on two receivers while RAKE data is collected on the other two receivers. The two transmit frequencies associated with high power amplifier (HPA) 1 and 2 are different. RSL data is measured on all four paths.

2.2.3.2 Quad RAKE

In this quadruple RAKE configuration, called "QURK," multipath delay spread is measured sequentially on receiver pairs 1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, and 3 and 4. The dashed lines replace the solid lines for transmit 2, receive 2, and receive 4 in figure 2-6, and no BER measurements are possible. Again, the two transmit frequencies are different. RSL data is measured on all four paths. This mode is used for final antenna alignment and for tracking variations in the lengths of the four paths during changing propagation conditions.

2.2.3.2 Space Quad Diversity

This mode can be either of the two configurations described above, except that the two transmit frequencies are identical. In this mode, the utility of single frequency quadruple space diversity

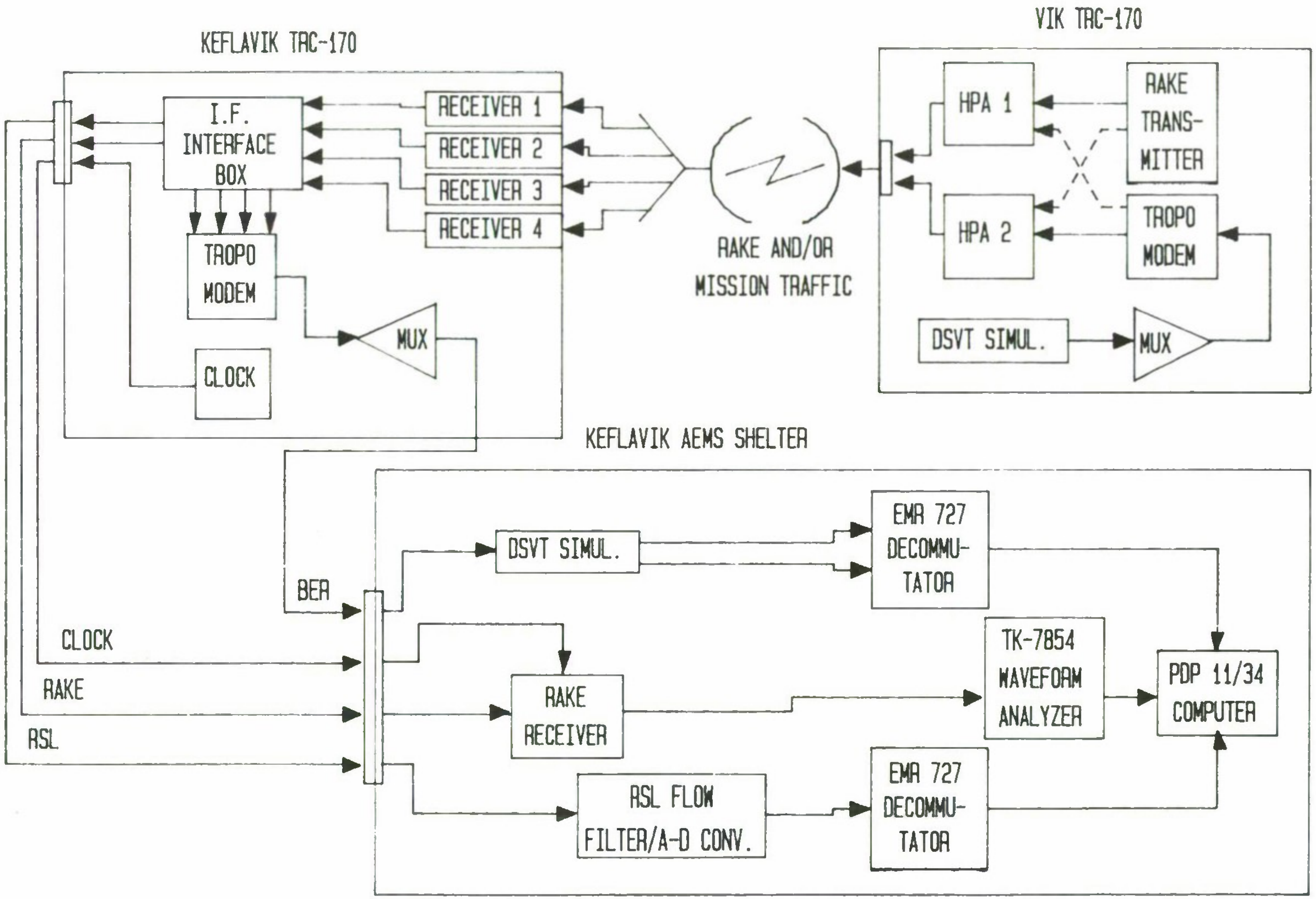


Figure 2-6. Test Configurations

is investigated for cases where the radio frequency (RF) spectrum is densely used. The horizontal and vertical polarizations are used to separate the data. They do not provide any diversity.

2.2.4 Measurement Parameters

The following parameters were measured for each 3-minute data run:

1.* Received signal level (RSL i.e., path loss)
2.* RSL peak-to-peak fading
3.* RSL fade rate and duration
4.* RSL fading correlation on six receiver pair combinations
5. Two-RMS multipath delay spread
6.* $2\sigma_m$ multipath delay spread
7. Differential path loss between diversity channels
8. Width of delay power spectrum 7 dB down from peak
9. Differential time-of-arrival between channels
10.* BER over a 32 kb/s digital telephone circuit.

Appendix B contains plots of the items marked with an asterisk (*) for the entire test period. The method used to measure the above parameters is briefly discussed in the following subsections.

2.2.4.1 Received Signal Level

The RSL for each receiver was monitored from the radio's 70 MHz IF (see figure 2-5) signal through log-linear amplifiers. RSL data was sampled 60 times/second for each of four receivers over a 3-minute timespan, and histograms were created from these samples. From these histograms, the median RSL, peak-to-peak fading, and distribution were determined.

2.2.4.1.1 RSL Fade Rate and Duration. The RSL fade rate and duration were calculated from the RSL samples by finding the negative and positive going crossings of the median over the 3-minute time-span. From the positive crossings, the average number of fades per second was calculated. The time between a negative crossing and the next positive crossing defined a fade, and a histogram of these times was saved in the data base.

2.2.4.1.2 RSL Fading Correlation. The zero time-shift correlation coefficient between each of the diversity paths was calculated for each 3-minute period.

2.2.4.1.3 Path Loss. The path loss was determined from the median RSL and the known equipment parameters from table 2.2 using the following equation:

$$PL = P_{TX} + G_T + G_R - RSL - L_E$$

where:

P_{TX} = Transmit Power (dBm)
G_T = Transmit Antenna Gain (40 dB)
G_R = Receive Antenna Gain (40 dB)
RSL = Receive Signal Level (dBm)
L_E = Equipment Losses (1 dB)

The antenna gains (G_T, G_R), and equipment losses (L_E), were assumed to be constant for the entire test. In figure 2-5, the calibration accounted for all gains and losses from the receiver input at the radio to the PDP 11/34 computer. The transmitted power

and calibrated RSL were recorded for each data run. The resulting path loss then provided a measure of path performance independent from system parameters.

2.2.4.1.4 Differential Path Loss. The differential path loss is the difference in median path loss between the different diversity paths. This parameter is particularly useful in analyzing changes in propagation due to antenna alignment, foreground effects, and antenna movement due to high winds and settling.

2.2.4.2 Multipath Delay Spread

The multipath delay spread data were measured using the Institute for Telecommunication Science (ITS) Troposcatter Channel Probe (RAKE) and a Tektronix 7854 programmable digitizing oscilloscope. Measuring the multipath spread of a troposcatter channel is identical to measuring its impulse response. (See appendix A for further discussion.) The RAKE system transmits a pseudorandom code at 10 MHz and compares it at the receiver with a replica of the original code. The codes are chosen such that the comparison circuitry will have an output proportional to the incoming RSL only when the codes match up and there is no output otherwise. By sliding the code at the receiver in time, relative to the transmitted waveform, and plotting the output of the correlator as a function of relative time delay, the impulse response of the channel is determined. For each data collection run, the delay power spectrum on each of two paths was obtained by averaging successive impulse responses over the 3-minute data-collection period.

2.2.4.2.1 Two-Root Mean Square Multipath Delay Spread. The two-root mean square (RMS) multipath delay spread is derived from the delay power spectrum. Its value approximates the 2σ value used in

literature, and it is valid when the peak of the RAKE response is more than 23 dB above the noise floor. A $2\sigma_m$ parameter, less sensitive to the effective RAKE response above the noise floor, is also computed. It assumes the response has a split-Gaussian distribution and is the sum of the lower and upper standard deviations. These metrics have been used throughout the current TRC-170 link engineering program.

2.2.4.2.2 Multipath Delay Spread 7 dB Down From the Peak. The 7 dB multipath delay spread is derived from the same averaged power impulse responses. It is calculated by measuring the width between the -7 dB points of the delay power spectrum. For a nondispersed response, the two-RMS and $2\sigma_m$ widths are about 3 dB down from the peak of the response. For a Gaussian response, the 7 dB width would be about 1.6 times as wide. For more complicated responses, the 7 dB width can be much wider.

Note that different tropo modem designs have different levels of sensitivity to multipath. The complete impulse power response is archived in the data base so that different measures of multipath spread can be calculated.

2.2.4.2.3 Differential Time-of-Arrival. This parameter measures the difference in the length of two propagation paths. (Note: One nanosecond is approximately equal to one foot of path length.) The effect of different arrival times of the same bit of information on different diversity paths may increase the effective multipath spread seen by the modem when a single clock recovery circuit is used. Its magnitude can be minimized by careful antenna alignment.

2.2.4.3 Bit Error Rate

The link bit error rate is measured by injecting a pseudorandom bit stream at the Vik TRC-170 site generated by a Digital Secure Voice Terminal (DSVT) Simulator, as shown in figures 2-5 and 2-6. This bit stream, emulating a 32 kb/s loop subscriber, is transmitted by the TRC-170 radio system and interfaced with a second DSVT Simulator, located in the AEMS shelter at Keflavik, monitoring the received bit pattern for errors. Clock and error data are reformatted by the EMR-727 Decommutator for input to the PDP 11/34 computer system.

2.3 WEATHER DATA

Twice-a-day radiosonde data was obtained from personnel at the Naval Air Station, Keflavik. It will be used, as appropriate, in creating a polar climate type in the tropo prediction programs discussed in section 3.

SECTION 3

LINK PREDICTIONS

This section first presents a brief background on the propagation models used to predict the performance of the two links discussed in this report. Then, the detailed predictions for both links are presented.

The principal parameters required for predicting path loss of troposcatter radio links are geometry of the propagation path, climatological factors, and frequency. Historically, multipath delay spread effects, known to cause degradation of performance in analog systems, were not treated explicitly in prediction models for such systems.

With the advent of digital troposcatter radios using adaptive modems (see appendix A for more detail), multipath delay spread has become an important parameter in predicting link performance. Adaptive modems adjust their response to the changing characteristics of the multipath delay spread and continuously compensate for the changing multipath. Since these operations have no significant effect on accompanying thermal noise, the useful signal-to-noise ratio of the signal is enhanced. Stated another way, as multipath delay spread (MDS) increases and the thermal noise level at the receiver input terminals remains constant, the minimum required RSL for a given bit error rate decreases. However, adaptive modems are limited in the amount of MDS they can tolerate because adjacent symbols in the binary data stream begin to overlap. The modems can function successfully only as long as individual symbols are not so

spread out in time by multipath delay that they extensively overlap neighboring symbols. When extensive overlap occurs, the RSL required for a given BER rises very sharply, and the modem's performance degrades.

Therefore, the performance of a link is dependent not only on the path loss, but also the multipath delay spread. As the AN/TRC-170 tactical troposcatter radio was finishing DT&E and IOT&E, the need to evaluate and validate the existing prediction models became apparent. As a result, a link engineering study comparing collected field data with a number of models was conducted. From this study, the Signatron "TROPO" program was determined to be the most accurate model. However, the MDS predictions obtained using "TROPO" were found to seriously underpredict the observations. MITRE then combined the "TROPO" path loss predictions with a modified (by actual field measurements) MDS prediction model. This model has been computerized for use on a personal computer and is known as the Site Analysis Tools (SAT). SAT represents the most accurate known prediction model for digital troposcatter performance in the 4.4 to 5.0 GHz frequency band.

3.1 PREDICTION PROGRAMS

This section provides background information on the Signatron and SAT programs used to predict the performance of the two Iceland links.

3.1.1 Signatron "TROPO"

The computer program "TROPO", developed under Defense Communications Agency Contract DCA100-80-C-0030, is intended to provide an accurate prediction model of the troposcatter and/or diffraction

propagation path. It is used to calculate the troposcatter path loss distribution and power per unit delay (multipath) profile of a specific troposcatter link and the correlation between diversity ports for various diversity configurations. The "TROPO" program can also predict the performance of the MD-918 modem, the AN/TRC-170 DAR-4 modem, or any other modem if a performance model is provided by the user.

"TROPO" has been implemented for both PDP-11/70 and IBM-370 operating environments. Since it was written in FORTRAN with some attention to portability, it can be adapted to other systems with little difficulty provided they support FORTRAN IV. "TROPO" is currently supported on a MITRE PDP 11/24 computer.

3.1.2 SAT

SAT is the personal computer (IBM compatible) version of the AN/TRC-170 Initial Link Engineering Manual. Link prediction results obtained using SAT parallel those obtained using the initial link engineering manual.

SAT is a menu-driven program segmented into individual screens allowing the link engineer to predict TRC-170 troposcatter performance. The two main functions, profiling and prediction, are treated as two separate processes. For each link, the profiling segment of the program must be completed prior to beginning the prediction segment because profiling information is used as input to the prediction process.

The predictions are presented in three different formats: supportable mission rate, path loss, and corresponding receiver signal level. In addition, the predicted multipath spreads and maximum usable mission rate are presented, to avoid intersymbol interference.

The multipath delay spread predictions are based on the "TROPO" program, but are modified to match the observations on six links measured in Florida and Arizona in support of the TRC-170 link engineering project. This modified model has accurately predicted MDS on other links in Korea, England, Florida, and Arizona.

Any computer system capable of running MS-DOS (version 2.1 or higher) with at least 256K bytes of memory, one floppy disk drive, and a graphics card (e.g., monochrome, CGA, EGA) can be used. In addition, a printer is useful for hard copy output.

3.2 PREDICTION RESULTS

All link predictions were generated using either the "TROPO" or SAT program. For the Vik-Keflavik link, SAT was used. Because SAT is limited to predictions in the 4.4-5.0 GHz frequency range, the Hofn-Dye 5 link was predicted using the "TROPO" program. Only path loss predictions were generated for the Hofn-Dye 5 link because MDS data was not available. All predictions are for a confidence (service probability) of 0.50 and the continental temperate climate type. The prediction models default to the continental temperate climate type when the polar climate type is selected because no variability functions currently exist for the polar climate type. The prediction values presented here will be referred to throughout the report. These values are plotted whenever measurements are presented to aid in understanding the data.

3.2.1 Vik-Keflavik

The appropriate parameters contained in table 2.3 and the profile shown in figure 2-1 were input to the SAT program. Table 3.1 shows the predicted path loss and MDS for different time availabilities.

Table 3.1. Predicted Performance for the Vik-Keflavik Link

Time Availability (%)	Path Loss (dB)	Multipath Delay Spread (nsec)
0.01	196	N/A
0.10	202	N/A
1.00	210	86
5.00	N/A	97
10.00	220	109
50.00	231	190
90.00	240	236
95.00	N/A	297
99.00	248	381
99.90	254	N/A
99.99	260	N/A

3.2.2 Hofn-Dye 5

The parameters in table 2.1 were used to obtain the path loss predictions shown in table 3.2 for the Hofn-Dye 5 link.

Table 3.2. Predicted Performance for the Hofn-Dye 5 Link

Time Availability (%)	Path Loss (dB)
0.01	217
0.10	222
1.00	227
10.00	235
50.00	243
90.00	248
99.00	252
99.90	255
99.99	258

SECTION 4

TEST RESULTS

This section presents the results of the data collected on the two Iceland links. The data were analyzed to determine how well the predictions agree with the actual measurements.

The detailed AEMS data on the Vik-Keflavik link, a total of 1664 data runs, are presented in appendix B. All data in this report were edited to exclude invalid runs caused by equipment or operator error. In addition, the data were edited by propagation mode, i.e., tropo, ducting, or mixed. For this link, 95 percent of the data were troposcatter mode, 5 percent were mixed mode, and no ducting propagation was observed. This editing process is also discussed in appendix B.

4.1 VIK-KEFLAVIK LINK

4.1.1 Multipath Delay Spread Distributions

Figure 4-1 presents all of the valid MDS data for receivers 1 and 3. The predicted MDS from table 3.1 is also shown on this figure. Insufficient MDS data were collected on receivers 2 and 4 to be statistically significant. Therefore, only data for receivers 1 and 3 are discussed. As the figure shows, the MDS on this link in Iceland is slightly less but in good agreement with that predicted.

To see if the MDS data contained any diurnal variability, distributions for four different time periods were generated; the four distributions are shown in figure 4-2. From this figure, no large changes are seen, even though the daily solar zenith angle change was near maximum during the September and October test period.

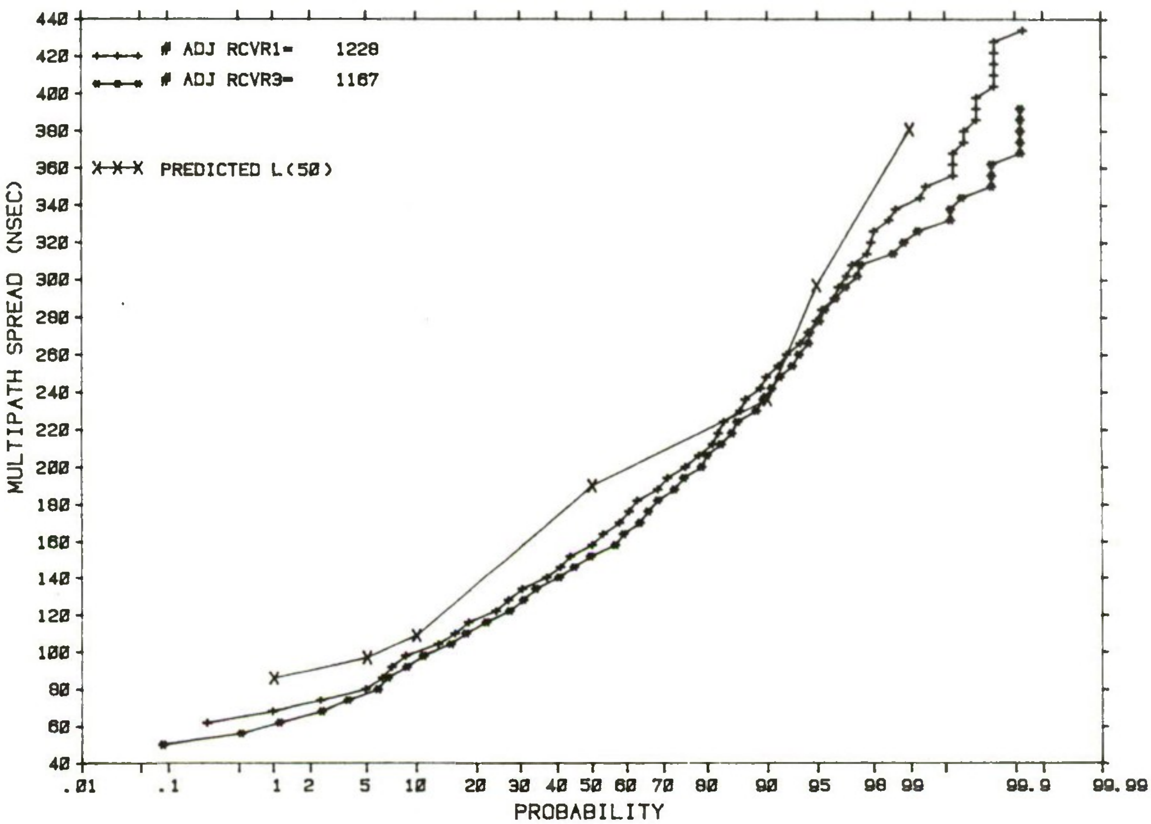
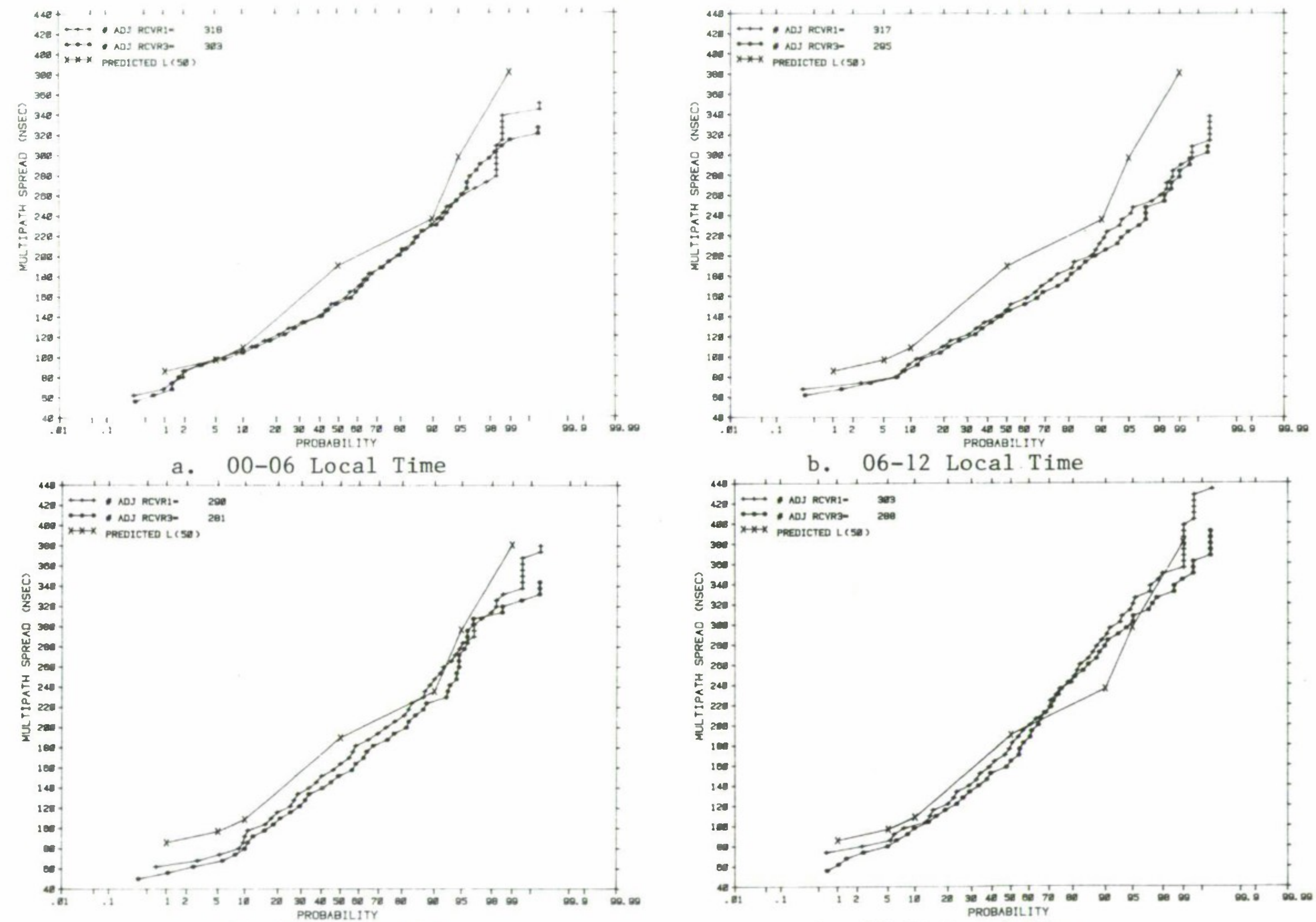


Figure 4-1. Multipath Delay Spread Distributions for All Data for Receivers 1 and 3



a. 00-06 Local Time

b. 06-12 Local Time

c. 12-18 Local Time

d. 18-24 Local Time

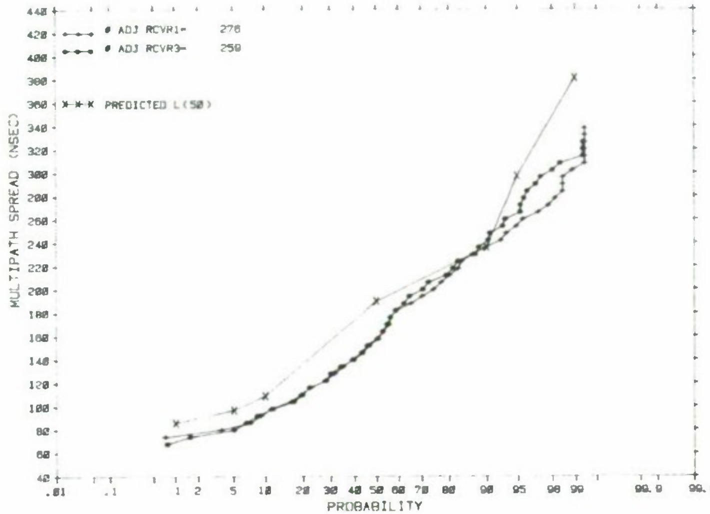
Figure 4-2. MDS Distributions by Time of Day

could occur between winter and summer, although it is believed these changes would still not have a significant effect on radio performance. Figure 4-3 shows the MDS distributions for each of the four test weeks. Again, the variability is small, although it is larger at the higher percentiles.

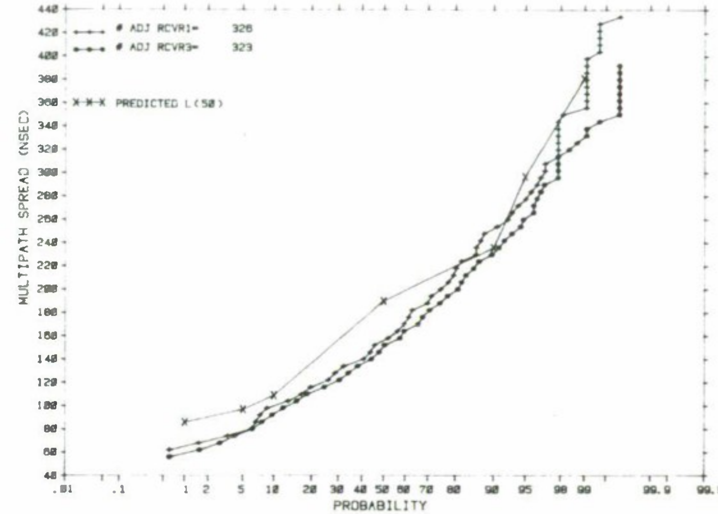
Table 4.1 summarizes the data seen in figures 4-1 through 4-3. When two values are shown for an entry, the MDS separation between receivers 1 and 3 (left, right values, respectively) was greater than 10 nanoseconds. Otherwise, the value shown is the average of the two receivers. The difference between the "Predicted" and measured "All" of about 40 nanoseconds at the 50th and 99th percentiles is not significant in terms of modem performance. The reason for receiver 1 observing somewhat more MDS than receiver 3 is unknown, but it is probably caused by antenna foreground effects that influence the effective antenna beamwidth. The variation in MDS from week to week and from time block to time block was small. The 06-12 time block had the least MDS, and the 18-24 time block had the most. Based on these data, digital modems supporting 60 channels would have been operating in an optimum performance region (where the modem provides maximum implicit diversity) for most of the test period.

4.1.2 Path Loss Distributions

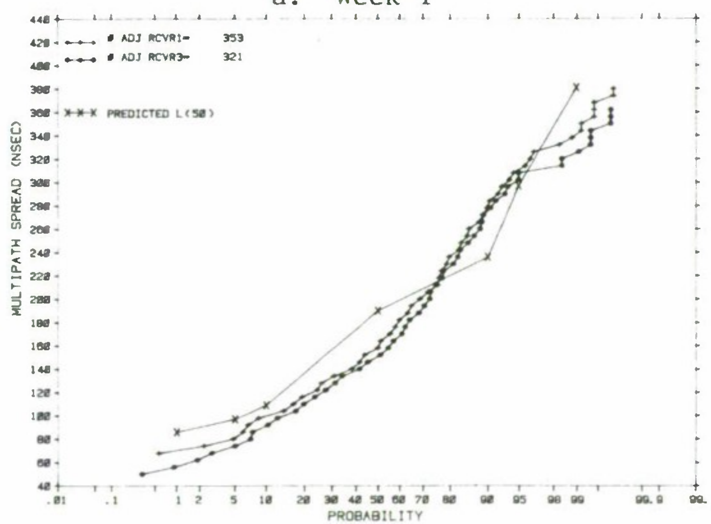
Figure 4-4 shows the path loss distribution by receiver for all valid AEMS data for the test. It also shows the predicted path loss from table 3.1. The immediate observation is that the path loss was greater than predicted throughout the test period. Figures 4-5 and 4-6 show the distributions for the four time blocks and each of the



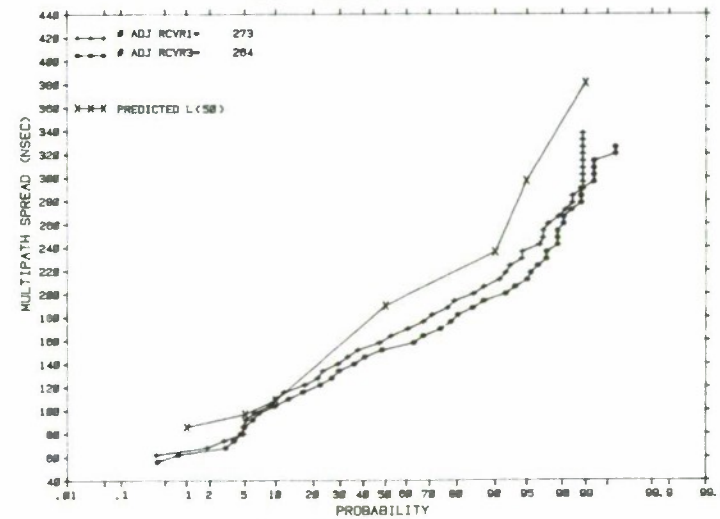
a. Week 1



b. Week 2



c. Week 3



d. Week 4

Figure 4-3. MDS Distributions by Test Week

test weeks, respectively. The 1800 to 2400 hours time frame (figure 4-5d) is the high loss period at greater than the 90th percentile. Week 2 (figure 4-6b) was the highest loss week of the test.

Table 4.1. Summary of Multipath Delay Spread

	Percentile		
	1	50	99
Predicted	86	190	381
All	63	155	342, 323
Local Time			
00-06	64	152	339, 314
06-12	67	145	290, 279
12-18	58	162, 151	335, 323
18-24	74, 60	177, 163	376, 344
Week			
1	70	156	307
2	59	152	356, 331
3	68, 54	153	340, 325
4	62	156	291

Note: All entries in nanoseconds.

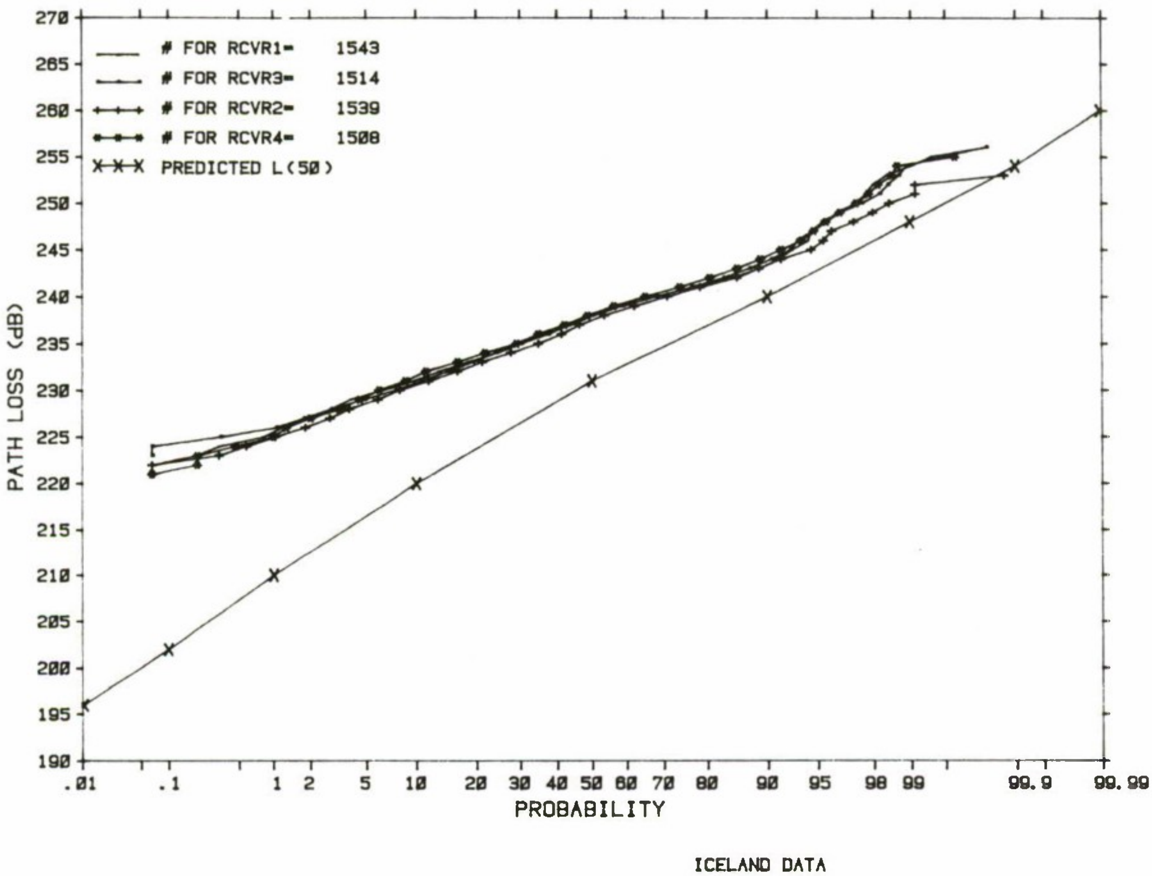
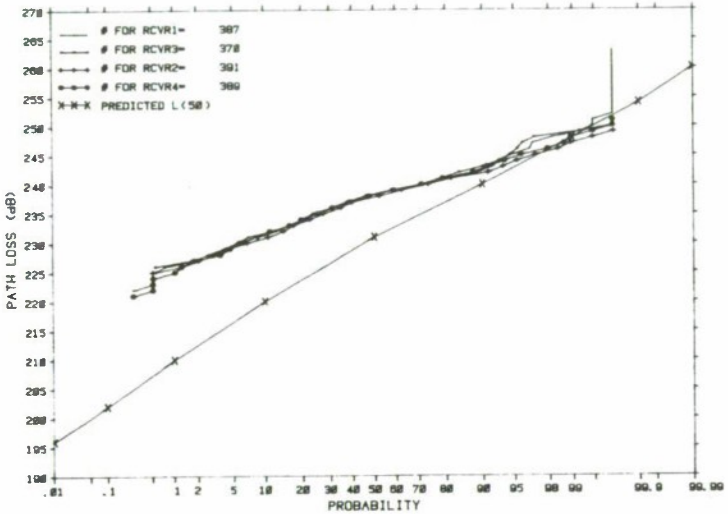
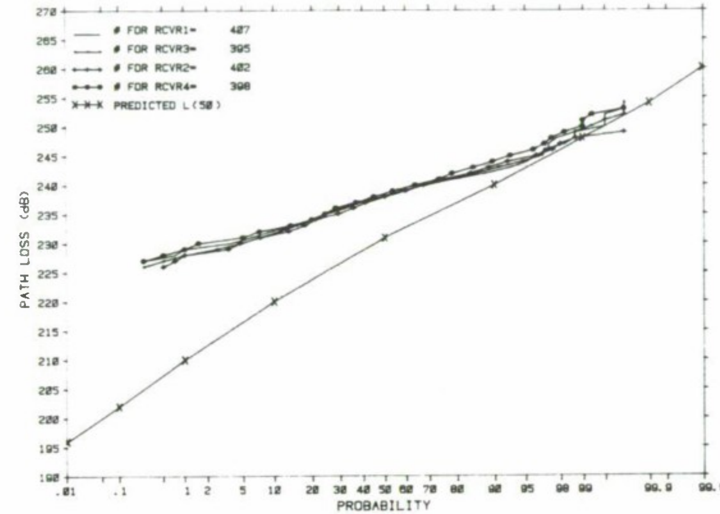


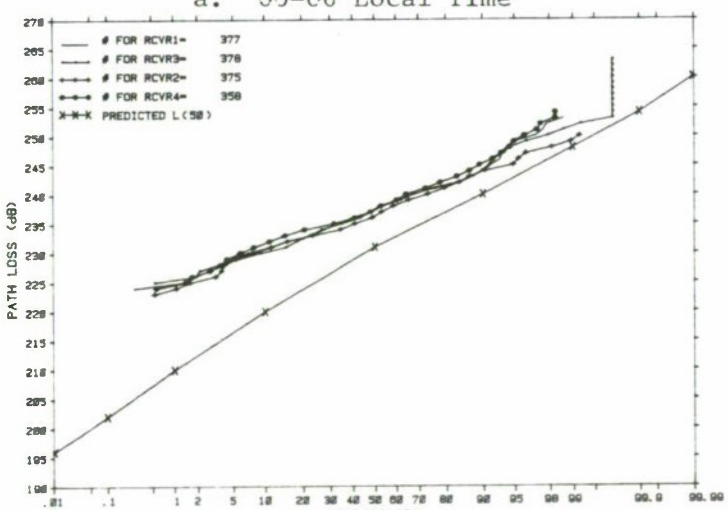
Figure 4-4. Path Loss Distributions for All Data



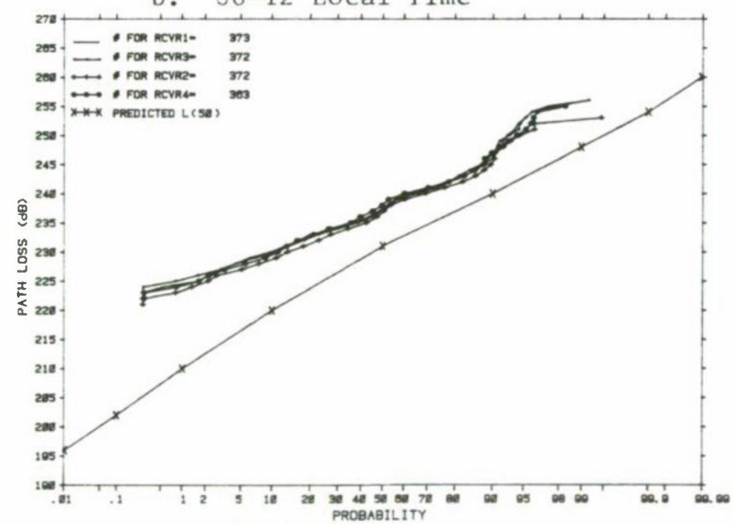
a. 00-06 Local Time



b. 06-12 Local Time

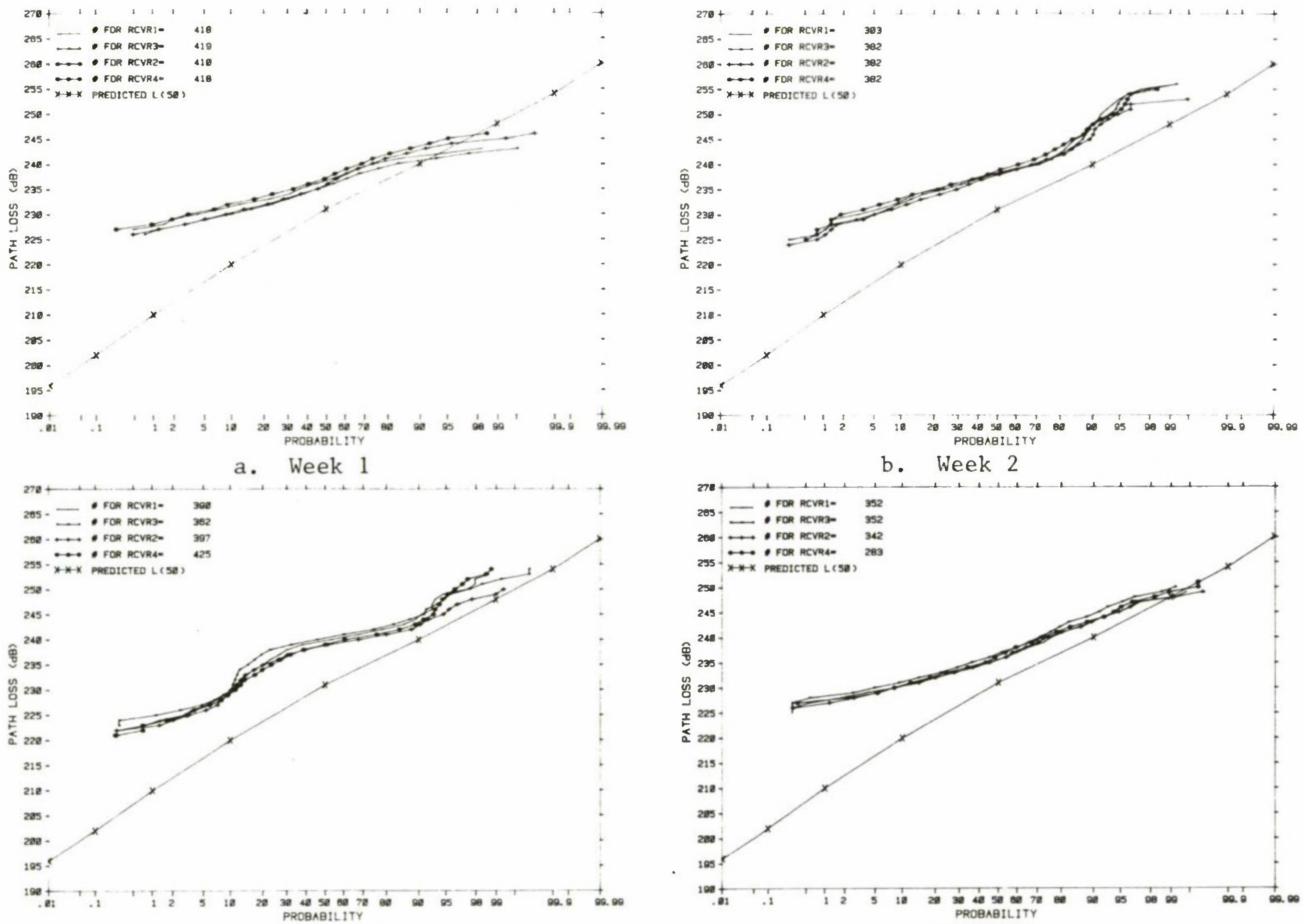


c. 12-18 Local Time



d. 18-24 Local Time

Figure 4-5. Path Loss Distributions by Time of Day



a. Week 1

b. Week 2

c. Week 3

d. Week 4

Figure 4-6. Path Loss Distributions by Test Week

Another observation is the different slopes, i.e., standard deviations of the measured and predicted data. These are likely due to lack of ducting on this link. Because prediction model variability functions do not exist for polar latitudes, the variability functions used in the prediction were for continental temperate latitudes, where the probability of ducting is believed to be one major contributor to these variability functions. Since ducting was not observed on this link, a discrepancy would be expected because strong signals were not received.

The region of primary concern on the distributions is the high path loss area because this is where link outages occur. Figure 4-7 was generated to get a more meaningful distribution. For each data run, the lowest path loss of the receivers was used to generate the minimum path loss distribution. In addition, the average path loss of the four receivers was used to generate the average path loss distribution. The minimum path loss distribution was generated because under fading signal conditions a maximum ratio tropo modem combiner will weigh most heavily the maximum signal (lowest path loss) for its decision. Thus, for the model adjustments presented in section 5, the minimum path loss (figure 4-7) will be used. Table 4.2 summarizes the path loss figures (least loss value of four receivers for figures 4-4, 4-5, and 4-6) by showing the path loss at probabilities of interest. As seen, neither of the distributions on figure 4-7 match the "All" distribution.

4.1.3 Joint Distribution of Path Loss and Multipath Delay Spread

Appendix A discusses the operation of digital tropo modems. As noted there, for a given BER the allowable path loss increases (or

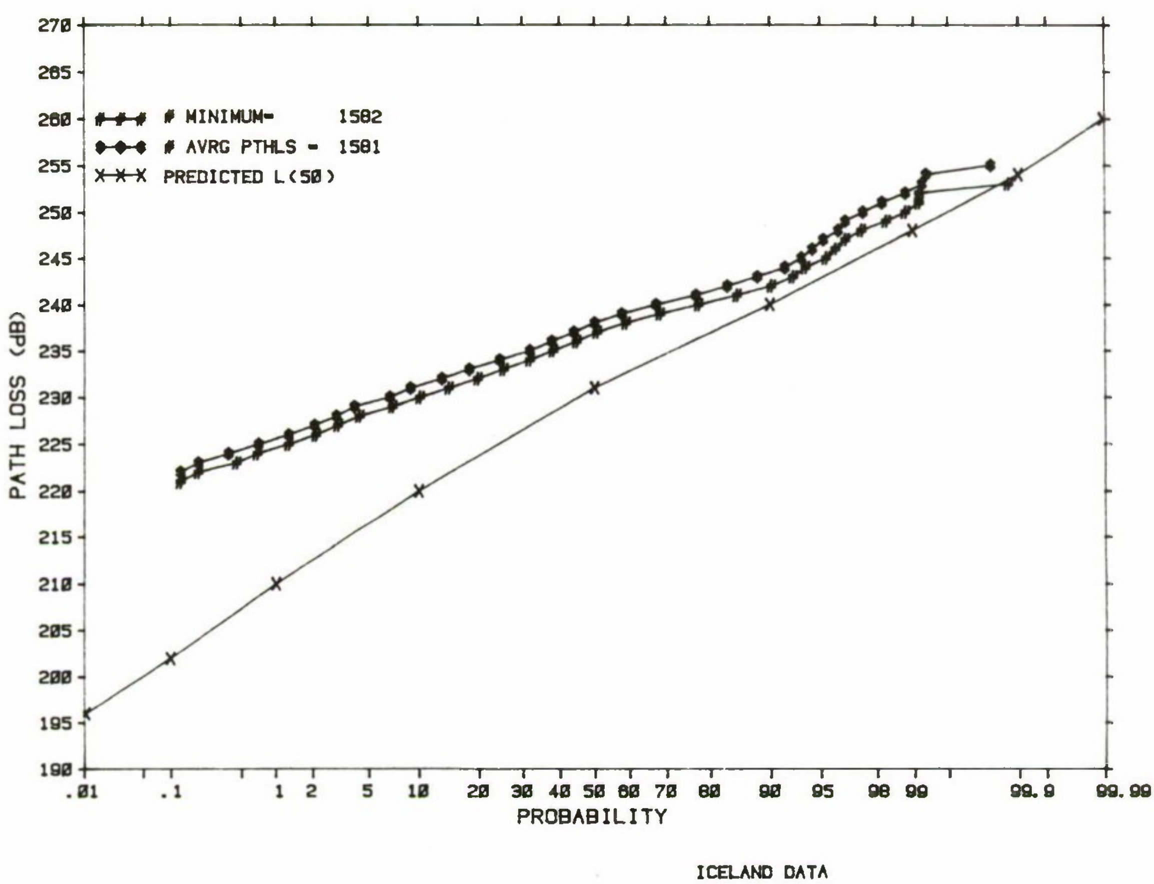


Figure 4-7. Path Loss Distribution for Average and Minimum of Four Receivers

Table 4.2. Summary of Path Loss for Vik-Keflavik

	Percentile			
	1	50	90	99
Predicted	210	231	240	248
All	224.6	237.7	243.3	250.9
Local Time				
00-06	224.7	237.8	241.7	246.9
06-12	227.8	237.8	242.1	248.1
12-18	223.8	236.2	244.0	244.4
18-24	223.0	236.5	245.3	252.8
Week				
1	226.2	235.6	240.4	242.6
2	225.4	237.8	241.0	252.8
3	222.7	238.8	242.8	249.1
4	226.6	235.7	243.2	247.9
Average	225.7	237.9	243.4	252.4
Minimum	224.4	236.7	241.9	250.4

Note: All entries in dB.

Path Loss (dB)

Correlation Coefficient = 0.247

Figure 4-8. Scatter Plot of Path Loss Versus MDS for Receiver 1


```
TOTAL = 1149                         PATH LOSS (dB)

 1149. SAMPLES
MEAN(X)=  238.34    VARIANCE(X)=    29.48    STANDARD DEVIATION(X)=    5.43
MEAN(Y)=  163.57    VARIANCE(Y)=  3348.72    STANDARD DEVIATION(Y)=   57.87
Y-INTERCEPT=  -384.43    SLOPE=  2.2992
CORRELATION COEFFICIENT=   0.216    COEFFICIENT OF DETERMINATION=  4.655

MPS MIN & MAX PTR & VAL:      1   42.98980          59   398.0063
PTH LOS MIN & MAX PTR & VAL:    33    223     67    257
```

Path Loss (dB)

Correlation Coefficient = 0.216

Figure 4-9. Scatter Plot of Path Loss Versus MDS for Receiver 3

RSL decreases) as the MDS increases until intersymbol interference is reached. Therefore, an additional system gain is obtained if path loss and MDS have a positive correlation. Figures 4-8 and 4-9 are scatter plots of these two parameters for receiver 1 (figure 4-8) and receiver 3 (figure 4-9). In these figures, the printed number is the number of occurrences in each cell (x, y coordinate on graph), with an asterisk indicating more than nine occurrences. The correlation for this 30-day period was about 0.23, typical of that measured on other links during the TRC-170 link engineering project.

4.2 PATH LOSS DISTRIBUTIONS: HOFN-DYE 5

Figure 4-10 presents the 2-year distribution of path loss for the years January-December 1982 and June 1985-May 1986 for the Hofn-Dye 5 800 MHz link. Also shown on this, and all following figures, is the predicted path loss from table 3.2. Each of the year's distributions are shown individually in figure 4-11. These two figures show that the predicted and measured path losses are in good agreement. For these 2 years, figure 4-11 indicates the year-to-year variability was very small. For the Vik-Keflavik link, the path loss in the 0.1 to 30 percentile range was greater than predicted. On the Hofn-Dye 5 link, it was less than predicted. Two factors probably contributed to this difference. Hofn-Dye 5 is a much longer link, 377 km versus 191 km, and the magnitude of the variability function decreases on longer links due to the probability of ducting decreasing. Also, a significant factor is that the distributions are for a complete year, while the Vik-Keflavik data is for only one month. Figure 4-12 shows the seasonal variability, and table 4.3 shows some statistics from the figures and the months included in each season. The standard deviations for both the lower (0.01-50) and upper (50-99.9) portions of the distributions are shown in addition to the standard deviations of the complete (0.01-99.99)

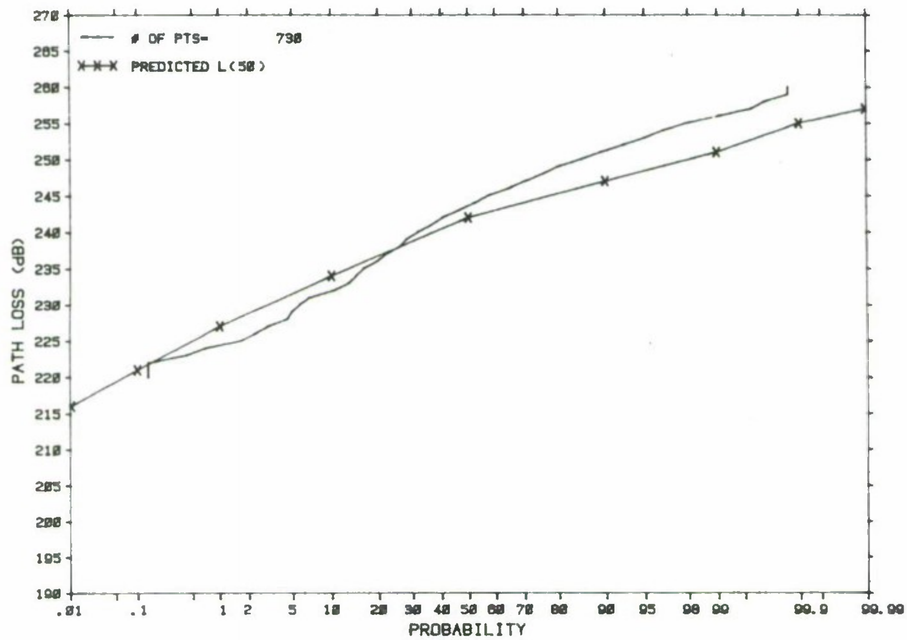


Figure 4-10. Hofn-Dye 5 Path Loss Distributions for 2-Years Data

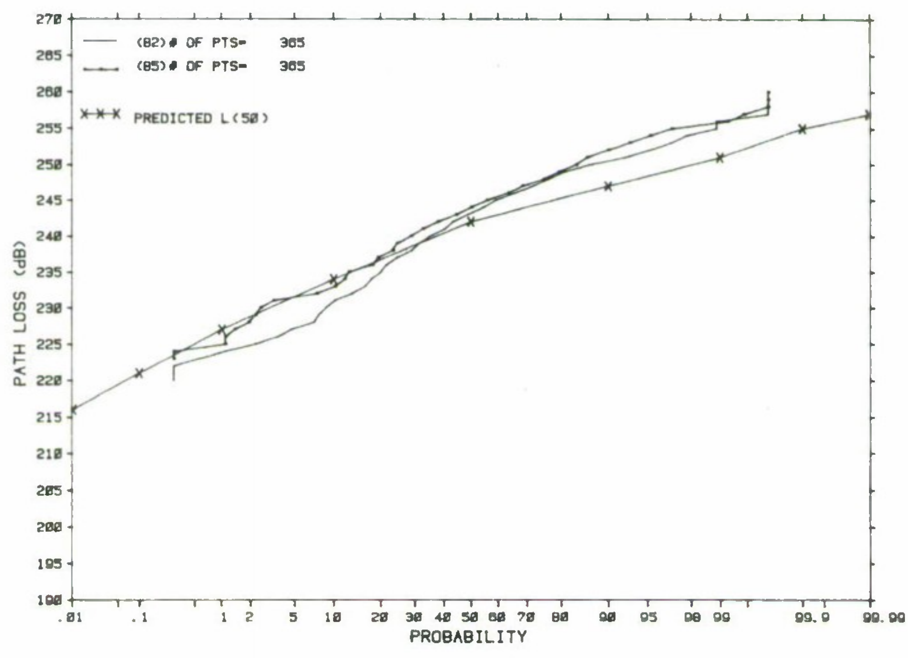
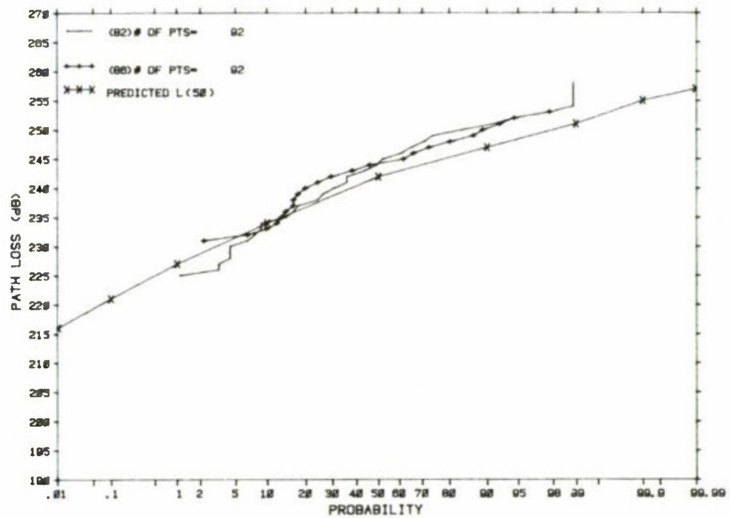
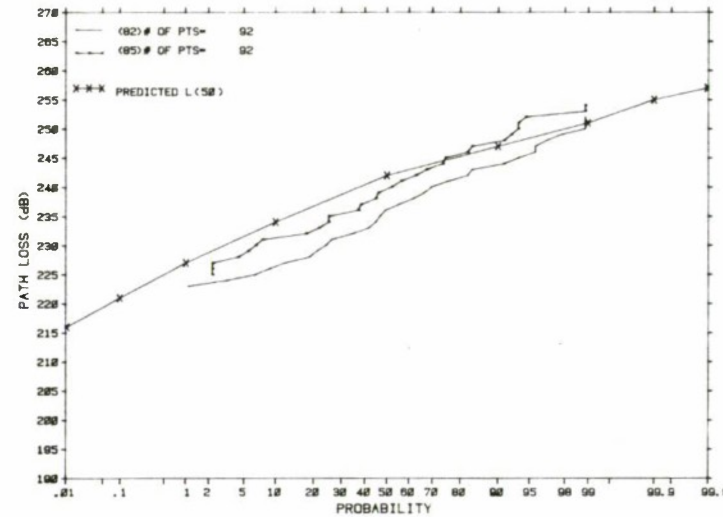


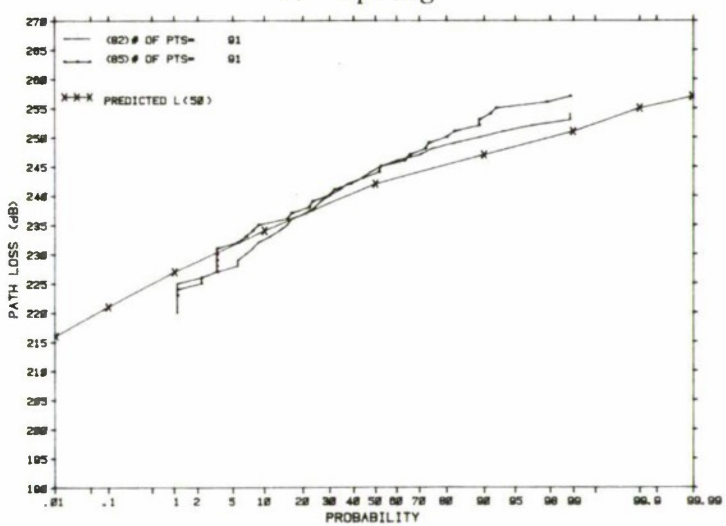
Figure 4-11. Hofn-Dye 5 Path Loss Distributions for Two Different Years



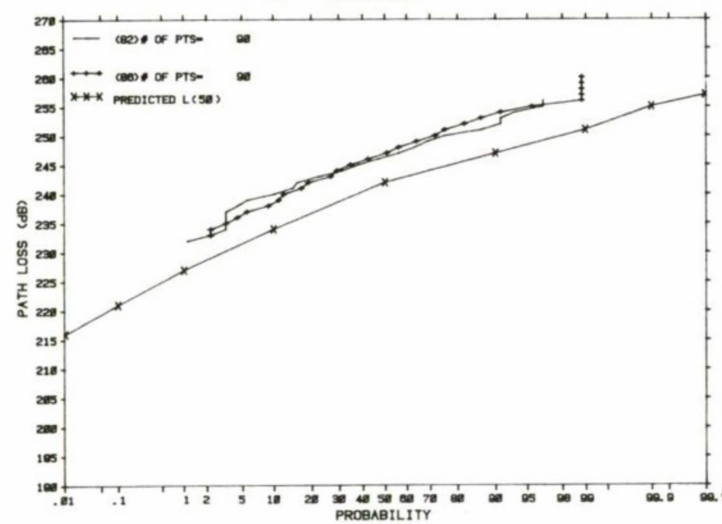
a. Spring



b. Summer



c. Fall



d. Winter

Figure 4-12. Hofn-Dye 5 Path Loss Distributions by Season

Table 4.3. Path Loss Summary for Hofn-Dye 5
1982 and 1985

Season/Path Loss	Median (dB)	Standard Deviation (dB)		
		0.01-50	0.01-99.99	50-99.99
Annual Predicted*	243	6.9	5.0	4.0
Spring	244.3	8.7	6.8	4.9
(Mar, Apr, May)	246.3	6.8	5.7	4.7
Summer	236.2	6.0	6.2	6.4
(Jun, Jul, Aug)	239.7	6.4	6.5	6.5
Fall	244.5	9.5	6.6	3.6
(Sep, Oct, Nov)	243.8	8.8	7.3	5.7
Winter	246.3	6.0	5.5	5.0
(Dec, Jan, Feb)	246.9	6.2	5.4	4.6

*"TROPO" program used to obtain these values using the L(50) values.

distributions. For each season, the first row is for 1982, and the second row is for 1985-86. From this seasonal data, winter is the high loss season, and summer is the low loss season. As does the Vik-Keflavik data, these data also indicate that a new variability function for Iceland should be generated, i.e., both the median and the standard deviation need to be adjusted.

SECTION 5

APPLICATION OF RESULTS

This section presents recommended adjustments to the path loss prediction model for the Iceland climate. To facilitate understanding the meaning of these adjustments, prediction terminology and the model adjustment methodology will be discussed first.

Two path loss model adjustments are presented. The first adjustment is at the 0.50 confidence and 0.99 time availability point, and the second is at the 0.90 confidence and 0.99 time availability point. Using the data from a single link (Vik-Keflavik) results in a new 0.50 confidence baseline. In addition, ESD requested to estimate the model adjustment required with 0.90 confidence. To do this, additional data from the Hofn-Dye 5 link and experience gained during the link engineering program were used.

The adjusted path loss model can be used to properly design links in Iceland or to justify the choice of other communications media. It is believed that no adjustments to the multipath spread model are required.

5.1 PATH LOSS PREDICTION TERMINOLOGY

The path loss predictions presented in this report use time availability and confidence (service probability) to quantify the prediction results. A working explanation of each term is detailed.

Time availability--The percentage of the hours in a year that the predicted path loss will not be exceeded. For example, if a path loss prediction is 240 dB at the 0.99

time availability point, the path loss will be 240 dB or less 99 percent of the hours in a year.

Confidence--Time availability would provide the complete prediction if the propagation model was comprehensive enough to give exact answers for all links. However, it is impractical to allow more detail for all the characteristics of the terrain and the atmosphere even if these parameters were known. The confidence concept is a method of taking prediction model, equipment, and antenna alignment uncertainties into account. The Defense Communications Agency uses a confidence level of 0.95 when engineering new links.

The three levels of confidence normally used are 0.50, 0.90, and 0.95. For each of these confidence levels, a set of time availability path losses are generated. The path loss predictions for the Vik-Keflavik and Hofn-Dye 5 links presented in this report are for a confidence of 0.50.

5.2 PATH LOSS MODEL ADJUSTMENT METHODOLOGY

It is outside the scope of this document to address the complete variability range (0.01 to 0.99) of path loss for a confidence of 0.50. Therefore, only adjustments to the 0.50 confidence, 0.99 time availability and 0.90 confidence, 0.99 time availability are addressed.

Section 4 shows that both the Hofn-Dye 5 and the Vik-Keflavik links underperformed their respective 0.50 confidence predictions; therefore, some adjustment to the prediction model is required.

The methodology uses data obtained from the 5 GHz Vik-Keflavik link and the 800 MHz Hofn-Dye 5 link to arrive at an adjustment to the prediction model that applies specifically to 5 GHz links in Iceland at a time availability of 0.99.

The adjustment methodology to arrive at a prediction for 0.50 confidence, 0.99 time availability consisted of two major steps as detailed below:

Step 1

The one-month limitation of the Vik-Keflavik test raises the question of the relationship (difference) of the path loss distribution for that particular period to a yearly path loss distribution. This relationship is obtained by comparing the Hofn-Dye 5 data observed during the test period with that observed over a 2-year period for a given time availability. The resulting adjustment is:

(2-year Hofn-Dye 5 measured path loss) minus
(September-October Hofn-Dye 5 measured path loss)

Step 2

Although the Hofn-Dye 5 observations were taken on a different link at a different frequency, the difference in path loss between that link and Vik-Keflavik should be due principally to atmospheric conditions affecting propagation, which also apply to the Vik-Keflavik link.

The path loss difference (in dB) from step 1 is then assumed to apply to the Vik-Keflavik link. Therefore, the adjustment to the model should be:

> Adjusted path loss = predicted path loss + result of step 1 + (measured Vik-Keflavik path loss - predicted Vik-Keflavik path loss)

5.3 PATH LOSS MODEL ADJUSTMENT VALUES

5.3.1 0.50 Confidence, 0.99 Time Availability

The methodology presented in section 5.2 is now applied to the measured data. The test period Hofn-Dye 5 measured path loss, extrapolated to the 0.99 availability point, is 252 dB. The similarly defined measured path loss for 2 years was 254 dB; therefore, the step 1 value is 2 dB. For the Vik-Keflavik link, the model predicts 248 dB path loss while the measured value was 250.4 dB. Applying these values to the expression in step 2 results in a 4.4 dB greater path loss at 0.99 time availability with a 0.50 confidence factor.

5.3.2 0.90 Confidence, 0.99 Time Availability

Two methods were used to determine the higher confidence value of path loss for 0.99 time availability.

The spread in the once-a-day readings for the September-October test period for the three different years of Hofn-Dye 5 data, shown in figure 5-1, can be used to estimate a 0.90 confidence adjustment using

$$PL_{99,90} = 1.28\ \sigma_{99}$$

where σ_{99} is the standard deviation at the 99th percentile. However, insufficient samples were available in figure 5-1 to reach the 99th percentile, so the standard deviation at the points shown in table 5.1 will be used to derive a value. The result, 6.1 dB, is added to the 0.50 confidence, 0.99 time availability adjustment value of 4.4 dB to obtain an adjustment value of 10.5 dB.

Table 5.1. Path Loss Adjustments

Year	Time Availability 10%	50%	90%
1982	226.7	236.7	245.7
1985	235.3	246.5	254.3
1986	235.0	243.7	249.2
Average	232.3	242.3	249.3
Std. dev: σ	4.9	5.0	4.3
1.28σ	6.3	6.4	5.5

$$1.28\sigma = \left(\frac{5.5^2 + 6.4^2 + 6.3^2}{3}\right)^{1/2} = 6.1$$

Extrapolating on figure 5-1 leads to uncertainties in the results. To minimize the uncertainty, another approach is to assume that the 4.4 dB adjustment from section 5.3.1 is additive in the 0.99 time availability column for all confidence levels.

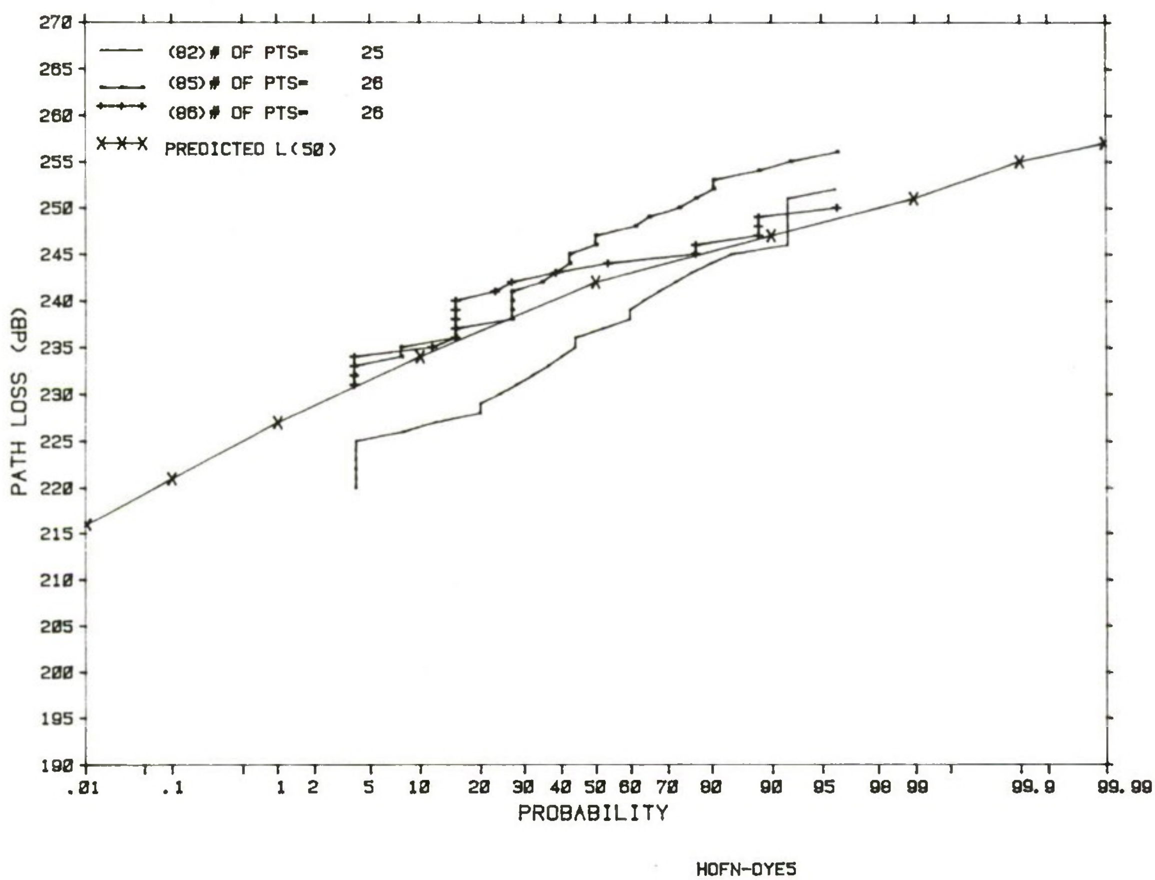


Figure 5-1. Path Loss Distributions for Three Different Years

This is a valid assumption since the prediction model uses the 0.50 confidence values for time availabilities of 0.50, 0.90, and 0.99 in conjunction with a statistical function to predict values for 0.90 and 0.95 confidence levels. While not presented earlier in this report, there is an additional loss of 9 dB predicted for the 0.90 confidence, 0.99 time availability. This 9 dB would be added to the 4.4 dB adjustment for a total adjustment of 13.4 dB.

In considering which of these values (10.5 dB or 13.4 dB) to use, the following points should be considered. From field experience and past test data, MITRE believes that the use of 0.90 confidence predictions almost always results in over-engineering a link. Therefore, the only time 0.90 confidence predictions are used is when there are no data or experience with the particular climate type in question. Because of the extrapolation uncertainty, the 6.1 dB from table 5.1 may be in error. However, sufficient understanding of tropospheric scatter propagation in Iceland has been obtained from this test to justify recommending the average of the two adjustments, 12 dB.

5.4 CONCLUSIONS

The MITRE tropospheric scatter link engineering program has combined the results of computer predictions with empirical data to obtain reliable estimates of tropospheric scatter link performance. However, until now, regional data has not been available to provide accurate C-band predictions of link performance in climates such as Iceland. Therefore, MITRE conducted a test and analysis program recorded herein to ascertain the expected performance of tropospheric

scatter radio transmission in the Icelandic environment. This program considered both path loss and MDS. The objective of this project was to derive the necessary adjustments to existing computer prediction programs to obtain predictions valid for the Icelandic environment.

The approach taken to obtain adjustment factors was to combine the results of a 1-month test program on a single C-band link with 2-year data from the Hofn-Dye 5 800 MHz operational link. Comparison of the data from the 1-month C-band test with predictions for the same link showed that an adjustment was needed. Combining the information from the C-band test link with the 800 MHz link resulted in an adjustment of 4.4 dB required to obtain a C-band path loss for 0.99 time availability at the 0.50 confidence level. Using the extrapolated 800 MHz data for two complete years resulted in a total adjustment of 10.5 dB to the C-band path loss required to achieve a 0.99 time availability at the 0.90 confidence level. The difference between the predicted 0.90 confidence and 0.50 confidence C-band path loss at 0.99 time availability, 9 dB, when added to the initial 4.4 dB adjustment, results in an adjustment of 13.4 dB. To be conservative, an average of the two adjustments is recommended. This results in a final recommended adjustment of 12 dB to the 0.50 confidence, 0.99 time availability path loss to achieve 0.90 confidence.

Measurements of MDS agree with those predicted and no adjustment is required or recommended.

APPENDIX A

PERFORMANCE CHARACTERISTICS OF THE TROPO MODEM

The principal input parameters required by classical techniques for forecasting the performance of analog troposcatter radio links are the geometry of the propagation path, radio equipment performance parameters, climatological and seasonal factors, and the carrier frequency. Analyses based on these parameters and on an extensive and well-established empirical data base of worldwide path loss statistics predict numerical values for statistical measures of the quality of link performance.

A.1 EFFECTS OF MULTIPATH PROPAGATION ON ANALOG SYSTEMS

Although they do affect performance, multipath effects are not treated explicitly in most analytical techniques for predicting the performance of an analog troposcatter radio system. In Frequency Division Multiplex/Frequency Modulation (FDM/FM) systems, multipath distortion of the received signal becomes perceptible when the FM signal is demodulated. This "multiplexer noise" distortion appears in the multiplexed channels as additive noise. It takes the form of multipath delay spread (MDS). The higher channels suffer more degradation from this cause than do the lower ones, and the degree to which system performance is impaired by MDS is directly related to the number of multiplexed channels present.

The effect of MDS on the performance of an FDM/FM system is shown in figure A-1. Here, for very low MDS, the required RSL for a given grade of service is determined by the noise floor of the radio equipment and is independent of any multipath effects. As MDS

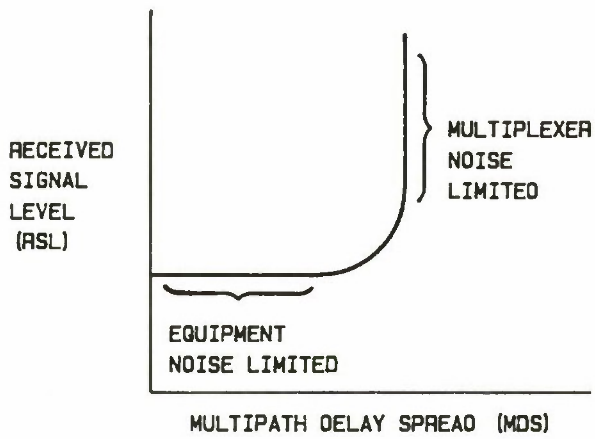


Figure A-1.
ANALOG FDM/FM
RSL VS. MULTIPATH TO ACHIEVE
A GIVEN LEVEL OF QUALITY

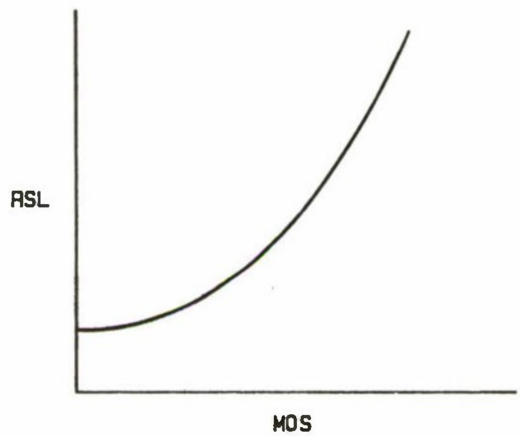


Figure A-2.
DIGITAL FSK, NON-ADAPTIVE MODEM
RSL VS. MDS TO ACHIEVE A GIVEN
BIT ERROR RATE

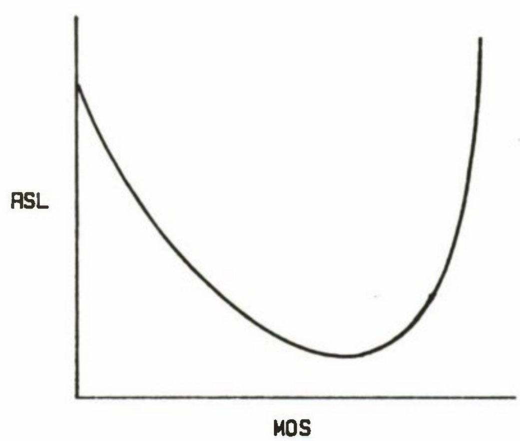


Figure A-3.
DIGITAL ADAPTIVE MODEM
RSL VS. MDS TO ACHIEVE A GIVEN
BIT ERROR RATE

increases, the multiplexer noise combines with thermal noise to increase the RSL required to maintain the prescribed grade of service. When the multiplexer noise is dominant, increases in RSL provide no improvement in system performance. Therefore, for a given equipment configuration and prescribed grade of service, there is a maximum allowable level of MDS. If it exceeds this level, it will be impossible to maintain the prescribed grade of service no matter how high the RSL. Since there are no proven techniques for predicting this level, it is customary to engineer FDM/FM analog troposcatter links to avoid paths judged likely to yield excessive MDS, using past experience as a guide.

A.2 EFFECTS OF MULTIPATH PROPAGATION ON DIGITAL SYSTEMS

In simple digital troposcatter systems, similar effects occur. Figure A-2 illustrates the effect on a basic frequency shift keying (FSK) modem. As the MDS increases for a given transmission rate, each transmitted symbol is spread out until it begins to overlap the following symbol. Intersymbol interference ensues, and the binary detection circuits begin to produce wrong decisions. As these errors are not caused by the presence of thermal noise, increased RSL does not reduce the frequency of their occurrence. Therefore, for any given data transmission rate and MDS, there is an error rate which is irreducible; that is to say, the presence of MDS limits system performance in such a way that neither increasing the transmitter power nor reducing the receiver noise figure improves performance.

A.2.1 Adaptive Modems

Recently, modems have been developed that determine the changing characteristics of multipath channels and continuously compensate the digital signals received through them for the differential time

delays they incurred during their passage. These "adaptive" modems, in effect, restore the received pulses to an approximation of the original shapes they had before entering the multipath channels by realigning their variously delayed components prior to the detection and decision processes. This not only restores the clear demarcations between adjacent pulses but also increases their amplitudes. Since these same operations have no significant effect on accompanying thermal noise, the signal-to-noise ratio of the signal is increased. Stated another way, as MDS increases and the thermal noise level at the receiver input terminals remains constant, the minimum required RSL for a given bit error rate (BER) decreases.

If they did no more than this and if there was no limit on the range of delays they could handle, adaptive modems would render system performance independent of MDS. Actually, adaptive modems are limited in the amount of MDS they can compensate. Their designs require separating adjacent pulses in the binary data stream by guard bands. Adaptive modems can function successfully only as long as individual pulses are not so spread out in time by multipath delay that these pulses extend across their guard bands and overlap neighboring pulses. When excessive spreading occurs, performance becomes similar to the FSK modem. Thus, as MDS increases, the required RSL for a given BER rises at an ever-increasing rate.

Figure A-3 illustrates the relationship between MDS and the minimum RSL required for a given BER when an adaptive modem is used in a digital troposcatter system. With no MDS, the required RSL is the same as for a simple Quadrature Phase-Shift Keying (QPSK) system. As MDS increases, the required RSL for a given BER drops. This drop continues throughout the range of multipath delay spreads that the modem is designed to compensate. Beyond this range, the effects of intersymbol interference become important, and the required RSL level

begins to increase. The increase is without limit since no amount of enhanced signal level can overcome intersymbol interference once the overlapping of symbols becomes too severe.

A.2.2 Implicit Diversity

The alignment and utilization by adaptive modems of signals arriving over a number of discrete paths through the troposphere constitutes a form of space-diversity operation. The diversity gain appears in the form of the aforementioned improvement in RSL. This diversity effect is implicit in the modem and is independent of any diversity simultaneously achieved through use of conventional space- or frequency-diversity techniques. It has been termed <u>implicit diversity</u> to distinguish it from the form of diversity achieved through more usual techniques. The latter might be called <u>explicit diversity</u>.

In all diversity systems, the benefits of increasing the order of diversity decrease for high orders of diversity. This is also true for adaptive modems used in conjunction with explicit diversity techniques. Thus, in a dual-diversity troposcatter system such as the AN/TRC-170V(3), the variation in performance with MDS is much greater than in a quad-diversity system such as the AN/TRC-170.

A.2.3 Fading and Delay Power Spectra

If an ideally narrow pulse were transmitted over a troposcatter channel, multipath delay would spread the received pulse into a form such as the top waveform in figure A-4. This would be the impulse response of the channel during the time that pulse was being transmitted. If another pulse followed after a time interval of the order of 0.001 second, the profile of the second received pulse would have the same gross features as the first, differing only in fine detail.

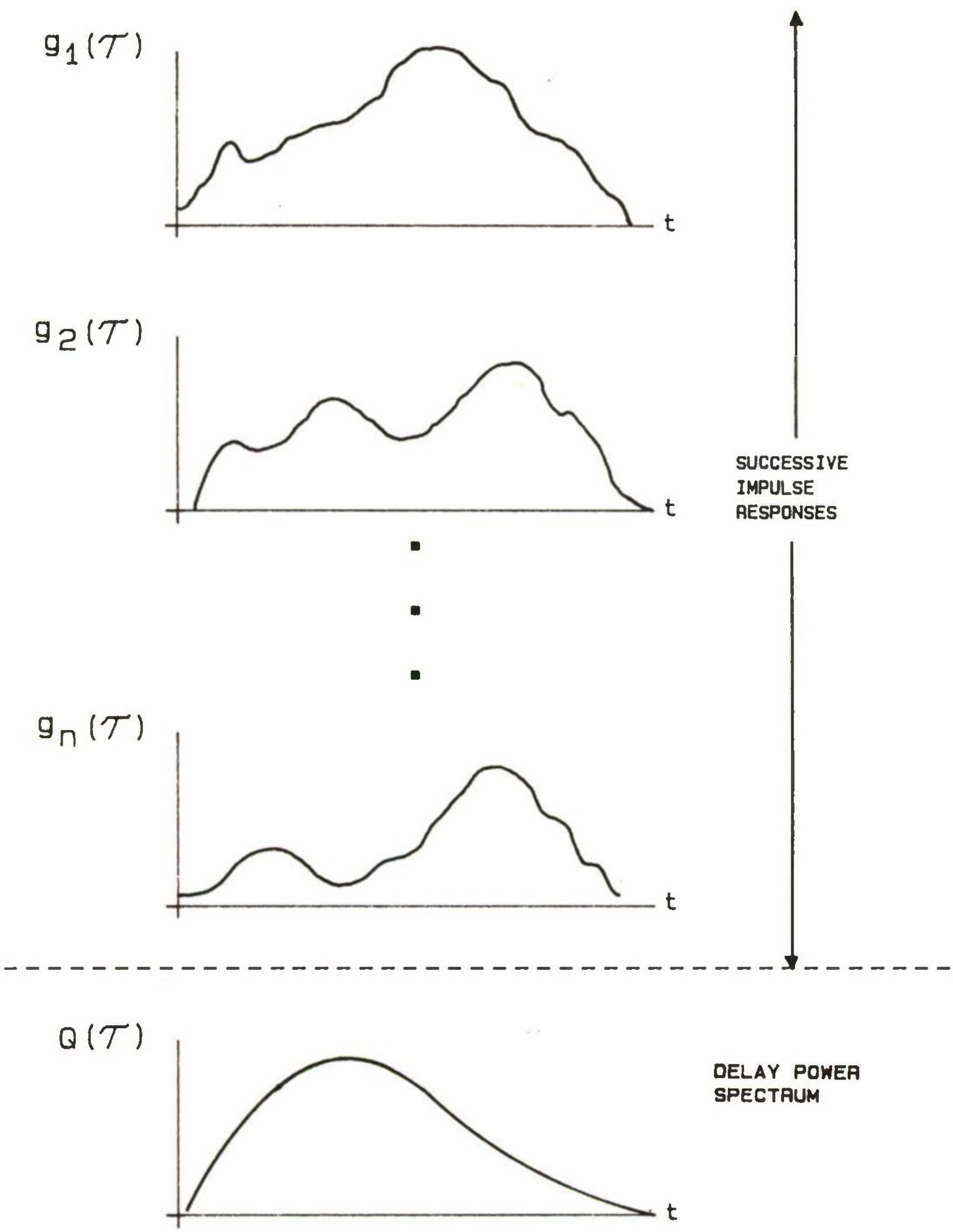


Figure A-4. Impulse Response and Delay Power Spectrum

It might appear as shown in the second waveform in figure A-4. This is because the atmospheric scattering elements would have moved only slightly during the intervening time. Over a sequence of pulses spanning a time interval of the order of 0.1 second, the gross features of the profile would begin to change. These changes take place at approximately the same rate as do the received signal variations in fast fading, namely, between 0.1 and 10 Hz. This is because both multipath effects and fast fading arise from the same random motion of scattering elements.

If a sufficient number of impulse responses spanning a time interval well in excess of 10 seconds are averaged, the effects of fast fading will have been essentially eliminated from the resulting profile. The resulting distribution, called the delay power spectrum, typically appears as shown at the bottom of figure A-4. The shape of the delay power spectrum is not constant in time but usually changes slowly over a span of minutes since it is subject to the same mechanisms causing slow fading.

A.2.4 Multipath Delay Spread

As a formal measure of the most useful attribute of the delay power spectrum, it is customary to define multipath delay spread not only as a phenomenon but also as a measure of its magnitude. It is defined most generally as twice the second moment of the delay power spectrum. Stated another way, it is twice the standard deviation of the products of the amplitudes comprising the delay power spectrum by their displacements from the mean of the distribution. In practice, each half of the delay power spectrum when divided at its peak approximates half of a normal probability distribution, each with its own standard deviation. The MDS is then taken as the sum of these standard deviations. This is usually designated the 2σ multipath delay spread.

A.2.5 AN/TRC-170 Performance Specifications

Performance characteristics for the AN/TRC-170V(2) and V(3) troposcatter radio terminals under conditions of rapid fading appear in table A.1. The terminals are required to yield bit error rates less than 10^{-5} under the prescribed combinations of multipath delay profiles, spectrum occupancies, data rates, and average path losses. Three standard multipath delay profiles (A, B, C) are defined by the shape of their delay power spectra in table A.2. For example, table A.1 shows that, given multipath profile C for a bandwidth of 3.5 MHz, a data rate of 1536 kb/s, and a set 2 [TRC-170(V2)], the allowable path loss is 237.8 dB to maintain a BER of 10^{-5}.

Table A.1. Average Path Loss (dB) for Which Average Bit Error Rate Shall be Less Than 10^{-5}

MULTIPATH PROFILE A

Bandwidth	3.5 MHz						7 MHz						
Trunk Data Rates, kb/s	128/ 256	144/ 288	512/ 576	1024/ 1152	1536	2048/ 2304	128/ 256	144/ 288	512/ 576	1024/ 1152	1536	2048/ 2304	4096/ 4608
Set 2	244.0	243.5	241.3	237.7	236.5	235.3	242.7	242.2	240.2	237.9	236.0	234.9	230.9
Set 3	226.5	226.0	223.4	218.4	216.5	216.1	226.2	225.7	224.2	221.9	220.1	219.1	213.4

MULTIPATH PROFILE 8

Bandwidth	3.5 MHz						7 MHz						
Trunk Data Rates, kb/s	128/ 256	144/ 288	512/ 576	1024/ 1152	1536	2048/ 2304	128/ 256	144/ 288	512/ 576	1024/ 1152	1536	2048/ 2304	4096/ 4608
Set 2	246.9	246.4	244.0	239.6	237.1	236.3	246.4	245.9	243.4	240.9	238.4	237.4	233.4
Set 3	233.4	232.9	230.4	223.7	220.9	221.0	233.5	233.0	231.2	228.5	225.3	224.5	217.7

MULTIPATH PROFILE C

Bandwidth	3.5 MHz						7 MHz						
Trunk Data Rates, kb/s	128/ 256	144/ 288	512/ 576	1024/ 1152	1536	2048/ 2304	128/ 256	144/ 288	512/ 576	1024/ 1152	1536	2048/ 2304	4096/ 4608
Set 2	248.0	247.5	245.1	240.4	237.8	237.1	247.6	247.1	244.3	241.5	238.5	236.3	232.7
Set 3	235.7	235.2	232.4	225.9	223.3	223.0	235.7	235.2	232.3	230.0	226.0	221.9	N/A*

*Set 3 will not operate at a 10^{-5} BER for this trunk rate.

Table A.2. Multipath Profiles

Relative Delay (nsec)	Relative Attenuation (dB) for Profile: A	B	C
100	0	0	3
200	16	3	0
300	38	7	1
400		12	3
500		17	5
600		23	7
700		29	10
800			12
900			15
1000			18
1100			21
1200			24
1300			27
2σ (nsec)	31	186	380

APPENDIX B

DETAILED AEMS DATA FROM ICELAND WITH DISCUSSION

This appendix presents the detailed AEMS data for the entire test. Table B.1 is a sequential list of the test configurations and the type of data collected by date and time. Refer to section 2.2.3 for a description of each test type. Figures B-1, B-2, B-3, and B-4 present detailed data covering weeks 1, 2, 3, and 4, respectively. The top curve in figures B-1 through B-4 is BER shown on a logarithmic scale from 10^{-1} to 10^{-7}. The next curve, multipath delay spread (TWO SIG), has a range of 50 to 500 nanoseconds. The path loss curves for receivers 1 and 3 (third curve from the top) and for receivers 2 and 4 on the next curve down are shown on a scale of 185 dB to 260 dB. The next three sets of curves are the correlation coefficients. For each set, zero is on the horizontal axis, and the range is plus and minus one. The following two curves are peak-to-peak fading for receiver pairs 1 and 3, and 2 and 4, respectively, with a range from 0 to 50 dB. The extra symbols (U and V) on the peak-to-peak fading curves indicate the signal faded into the instrumentation noise floor and, therefore, the true fading was as shown or larger. Finally, the bottom two curves are the fade rates for the same receiver pairs (1, 3, and 2, 4) with a range of 0 to 10 fades per second. Date and time are shown on the x axis of all figures. Each tick mark represents one hour.

Tables B.2, B.3, B.4, and B.5 present general weather observations for each test week. These were compiled from comments recorded in the data summaries and master station logs. While not quantitative by any means, they do provide a general feel for the weather conditions over the four-week test period.

Table B.1. Test Configurations

Date	Time	Test	Mission Rate kb/s	Comments
21 Sep 86	2006	BERK	512	
22 Sep 86	1037	QUBE	512	
22 Sep 86	1216	BERK	512	
24 Sep 86	1623	QURK	---	
25 Sep 86	1614	QURK		Space-space
26 Sep 86	1543			End of week 1
28 Sep 86	1659	QUBE	512	
28 Sep 86	1733	BERK	512	
1 Oct 86	1620	QURK	---	
1 Oct 86	2144	QURK		Begin high path loss
2 Oct 86	0203	QURK		End high path loss
2 Oct 86	1516	QURK		Begin high path loss
2 Oct 86	1847	BERK	256	
2 Oct 86	2143	DURK	---	Rx 2/4 CW, Rx 4 on 50 KHz filter End high path loss
3 Oct 86	0309	BERK	256	
3 Oct 86	0904	BERK	512	
3 Oct 86	1542			End of week 2
5 Oct 86	1609	BERK	512	
5 Oct 86	1016	BERK	512	High path loss
6 Oct 86	1651	BERK	512	End high path loss
8 Oct 86	2016	QURK	—	
9 Oct 86	1616	QURK		Space-space
10 Oct 86	0918			Begin high path loss
10 Oct 86	1130			End of week 3 & high path loss
12 Oct 86	1725	BERK	512	
14 Oct 86	0314	QURK		Space-space
14 Oct 86	1618	BERK	512	
14 Oct 86	2215	BERK		Rx 4 down, no diversity BER
15 Oct 86	1012	DURK		
15 Oct 86	1220	BERK	512	
15 Oct 86	1650	QURK		Space-space
16 Oct 86	1533	DURK		2/4 CW, 4 on 50 KHz filter
16 Oct 86	1740	QURK		
16 Oct 86	2127	DURK		2/4 CW, 4 on 50 KHz filter
17 Oct 86	0150	QURK		
17 Oct 86	0307	DURK		2/4 CW, 4 on 50 KHz filter
17 Oct 86	0618	QURK		
17 Oct 86	1725			End of week 4 & test

Table B.2. Weather Comments
Week 1

Date	Time	Keflavik	Vik
9-22	0400	Thin high clouds, cold	Cloudy, no wind
	0600	Light rain starting	Partly cloudy
	0730	Rain stopped	Cloudy
	1100	Horizon not visible, misty outside	Cloudy, slight wind
	1330	Surrounded by fog	Light drizzle
	2300	Cool and clear	Very windy with rain
9-23	0300	Clear	Mild winds, light rain
	1030	Mostly cloudy	Clear
	1200	Cold and windy	Clear, cold, and windy
	1600	Partly cloudy	Partly cloudy, cold and windy
	2000	Calm, slightly overcast	Partly cloudy, no wind
	2350	No wind, overcast	Cloudy, slight wind to the north
9-24	0400	Light cloud cover, no wind	Cloudy, slight northerly breeze
	0520	Slight rain	Rain and cold
	0800	Breezy and rain	Light rain and slight wind
	1200	Windy and rainy	Slight wind and rain
	1530	Wind at 30 MPH, gusting higher	Light rain, heavy clouds, slight wind
	2330	Windy, slight drizzle	Light rain, fog
9-25	0400	Windy and cloudy	Windy and cloudy
	0800	Windy, rainy and cold, some fog	Cloudy, light drizzle
	1200	Windy but clear	Cloudy, wind and rain
	2000	Windy and light rain	Cloudy, wind and rain
	2350	Clear, slight wind	Light rain, windy, visibility 12 feet
9-26	0400	Windy and cloudy	Light rain, heavy wind with visibility 15 feet
	0830	High winds, wet & cold	Rainy, windy with low visibility
	1200	High winds, wet & cold	Rainy and windy
	1500	Wind slowed to 15 MPH	Rainy

Table B.3. Weather Comments
Week 2

Date	Time	Keflavik	Vik
9-28	2000	Partly cloudy, light breeze, chilly	Cloudy and windy
	2350	Moderate winds and partly cloudy to clear	Partly cloudy with slight wind
9-29	0400	Cloudy and breezy	Cloudy with light rain mixed with snow flurries
	0800	Overcast and cool	Light rain mixed with snow
	1130	Light rain, cold and windy	Light rain with snow
	1550	Prime power out at 1300 because of high winds and rain	High winds and rain
	2000	Still windy, rainy and cloudy	High winds, drizzle and cloudy
	2330	Windy and rainy	Windy and cloudy
9-30	0400	Windy and cloudy	Extreme high winds
	0830	Winds at 15 MPH, completely overcast with rain	Extreme high winds with light clouds
	1200	Windy with rain	Winds at 80 MPH with hail. Lost RAKE because winds moved antenna 2.
	1300	Windy with rain Shut down at Vik	Shut down because of 90 MPH winds.
	1600	Winds at Vik still too severe	Hazard to be in maintenance shelter due to wind
	2000	Vik winds slowed, back on the air	Hazardous winds gone, realignment of antennas complete
10-1	0400	Cloudy, light winds and no rain	Cloudy, light rain and heavy wind
	0800	Cloudy, windy and light rain	Cloudy with rain
	1200	No wind, weather clearing, light drizzle	Cloudy with rain, but no wind

Table B.3. (Concluded)

Date	Time	Keflavik	Vik
	1630	Snowing between here and Vik (about 2 inches)	Winds are starting again
	2000	Snowing	High winds with clouds
10-2	0400	Snowing with light wind	Clear, cold with light breeze
	0830	Clear	Light snow, no wind and very cold
	1200	Cold, clear and no wind	Light clouds, no wind and cold
	1600	Clear and sunny	Beautiful weather
	2000	Clear skies and calm	Clear and calm
10-3	0400	Cold and clear with a light breeze	Clear with no wind
	0750	Cold and clear	Cold and clear
	1200	Cold and clear	Cold and clear
	1600	Cool, clear with 34°F	Cloudy but calm

Table B.4. Weather Comments
Week 3

Date	Time	Keflavik	Vik
10-5	1600	Foggy, rainy and $50^{o}F$	Cloudy
	1900	Cloudy, rainy and getting windy	Overcast and windy
	2350	Windy, getting colder	Overcast and high wind
10-6	0400	Cloudy, windy and cool	Cloudy, windy and cool
	0810	Clear, sunny and light wind	Clear with light wind
	1220	Clear, sunny and light wind	Clear with light wind
	1600	Clear with light wind	Clear with light wind
	2030	Overcast with some wind	Overcast and breezy
10-7	0400	Cloudy and cold	Light overcast and cold
	0800	Windy and cloudy	Cloudy and cold
	1200	Windy and cloudy	Cloudy and cold
	1600	Windy and cloudy	Cloudy and cold
	1950	Windy and cloudy	Windy and cloudy
	2350	Windy and cloudy	Windy, cloudy and rainy
10-8	0130	High winds	Windy and rainy
	0400	Very windy with rain	Windy, cloudy and rain
	0850	Too windy to risk role-yoke adjustment; rainy	Windy and rainy
	1210	Cloudy, cool, light wind and no rain	Cloudy, cold and no rain
	1600	Foggy, misty, and no wind	Cloudy, nice with no wind
	2000	Cloudy	Cloudy and light rain
	2350	Cloudy	Cold, windy and rainy
10-9	0400	Light winds and rain	Cloudy, windy and rainy
	0800	Cloudy, cool and breezy	Cloudy
	1030	Cloudy	Waveguide on HPA 1 burned out due to moisture.
	1550	Slight wind, fog and cloudy	Cloudy with wind
	2000	Cloudy with drizzle	Slight winds and cloudy

Table B.4. (Concluded)

Date	Time	Keflavik	Vik
10-10	0400	Cool and partly cloudy	Cool, overcast and light breeze
	0800	Drizzle, light wind with heavy overcast	High winds, rainy and cloudy
	1200	Light wind and rain. Shut down due to winds at Vik.	Shut down due to high winds.

Table B.5. Weather Comments
Week 4

Date	Time	Keflavik	Vik
10-12	1630	Rainy, hail and strong winds	High winds, rainy with hail
	2000	Slight wind and overcast	Severe winds and cold
	2350	Light wind and rain	Waveguide problems on HPA 2 due to high winds
10-13	0430	Light winds and rain	Severe winds and overcast
	0740	Windy and cloudy, no rain	Windy and cloudy
	1200	Light wind, very cloudy but no rain	Light wind and cloudy
	1550	Mild wind, cloudy and light rain	Mild winds, cloudy and light rain
	2000	Cloudy and light breeze	Moderate winds, light clouds and cool. Still some waveguide problems.
	2350	Cold, clear with light breeze	Moderate winds, cold and light rain
10-14	0400	Light breeze and partly cloudy	Slight wind, partly cloudy and cool
	0800	High winds and hail	Strong winds and cloudy
	1220	Slight wind, cloudy and cold	Strong winds and cloudy
	2000	Slight cloudiness but can see Northern lights	Power on HPA 2 down to 200 watts due to waveguide arcing caused by severe winds and hail
	2350	Slight cloudiness with wind	Weather conditions will allow the door of the maintenance shelter to be opened only an inch (severe wind).

Table B.5. (Concluded)

Date	Time	Keflavik	Vik
10-15	0400	Clear with light breeze	Clear and windy, but no rain
	0800	Clear with light breeze	Strong winds and cloudy
	1200	Clear	Very strong winds, cloudy and cold. HPA power down due to wind.
	1600	Snowing	Extremely strong wind, rain and hail
	1930	Overcast with some wind	Relocating to IPT building due to high winds
10-16	1200	Clear, cold and no wind	Clear and cold
	1630	Cloudy, rainy and no wind	Cloudy and rainy
	2000	Windy and rainy	Rainy, slight wind and cool
10-17	0400	Light wind and rain	Winds have increased
	0800	Severe winds, heavy rain and generally miserable	High winds and rain
	1200	Severe high winds	Severe high winds

Only valid data is presented in figures B-1 through B-4. Data taken during antenna alignment, after wind-induced antenna shifts, when RAKE profiles were not completely on the scope, or when the DSVT simulator (BER) lost sync (a total of approximately 100 runs) have been eliminated from the figures. However, all 1664 data collection periods exist on the detailed archived data tapes with appropriate edit codes.

The editing process allows valid subsets of a partially bad data run to be used. This can be seen on figure B-3, 8 October from 0200 to 0900 when antenna 2 at the Keflavik site moved due to high winds (see table B.4) causing the data on receivers 2 and 3 to be invalid. Receivers 1 and 4 were still graphed and used in the results; similarly, for the period from 8 October at 2330 to 9 October at 1030 when transmitter 1 at Vik failed.

The path loss and multipath delay spread distributions in the main body of the report were developed from the data seen in figures B-1 through B-4. These are the principal design parameters for digital tropo modems from which BER is derived and, thus, are of primary interest in link design.

B.1 PROPAGATION MODE

None of the data was classified as ducting during this test. The criteria for ducting mode is four out of six correlation coefficients greater than or equal to 0.25 while, simultaneously, two of the four peak-to-peak fade values are less than 12 dB. Looking at the figures and the correlation coefficient curves, it is evident ducting did not occur. During the periods when both transmitters were tuned to the same frequency (25 September at 1600 hours to 26 September at 1600 hours, for example), the crossing pair correla-

tion coefficient is expected to be higher, and the classification rules are different. On other 120-mile links in Florida and Europe, from 10 percent to 30 percent of the data was classified as ducting.

Although not used as a ducting criterion, fade rates have been observed to track propagation mode. For tropo propagation, the rates are typically greater than 0.5 fades per second (generally 1 to 5), and for ducting, they are typically 0.1 or 0.2 fades per second or less. When aircraft are in the propagation path and during storms, fade rates as high as 15 have been observed. Fade rates this high were not observed during the Iceland test. However, extended (longer duration than other tested links) periods of high fade rates (greater than 3) were observed. One cause for this could be Iceland's well mixed atmosphere. There was a noted correlation between high fade rates and high winds.

B.2 CONTINUOUS WAVE TRANSMISSION FOR HIGH PATH LOSS PERIODS

From 2 October at 2100 to 3 October at 0300 (figure B-2), transmitter 2 was placed in the continuous wave CW mode and a 50 kHz filter was used in the AEMS RSL chain. The increase of 15 dB in peak-to-peak fading on receiver 4 relative to receiver 2 is attributed to narrow band (50 kHz) versus wideband (5 MHz) fading. The primary purpose for using the CW mode was to increase the sensitivity of the RSL system allowing measurements during high path loss periods. During this period and on 6 October from 0930 to 1700, the 3-minute CW distributions of RSL were used to obtain median path loss values because the non-CW signals were near or below the AEMS noise floor.

B.3 CORRELATION COEFFICIENTS AND SPACE DIVERSITY

The description of the correlation coefficients legends (also see figure 2-6) is presented in table B.6.

Table B.6. Definition of Correlation Coefficients

Code	Type Paths	Transmitters	Receivers
P34	Parallel	1 and 2	3 and 4
X12	Crossing	1 and 2	1 and 2
C23	Converging	1 and 2	2 and 3
C14	Converging	1 and 2	1 and 4
D24	Diverging	2	2 and 4
D13	Diverging	1	1 and 3

The three runs on 25 September between 0900 and 1500 hours where the correlation coefficients jump from zero to about 0.5 with corresponding increases in peak-to-peak fading are due to airplanes in or near the common volume. The cause for the single jump, while all other pairs remained at or near zero, in the parallel pair correlation coefficient during this period, is unknown. Other instances like these also occurred during the last 3 weeks of the test.

The purpose of the space diversity test is to evaluate the effect of using identical transmit frequencies on quad diversity systems. The periods, 25 September at 1700 to 26 September at 1600 (figure B-1), 9 October at 1600 to 10 October at 1200 (figure B-3),

13 October at 1700 to 14 October at 0630 (figure B-4), and 16 October at 0700 to 17 October at 0500 (figure B-4), are periods when the space-space quad diversity configuration was used. This means that both transmitters operated on the same frequency. In this configuration, the correlation coefficient on the crossing path is in the 0.1 to 0.5 range. The crossing path correlation coefficient (X12 on the figures) was approximately 0.2 higher than observed on other links evaluated during the link engineering project.

B.4 BER PERFORMANCE AND IMPLICIT DIVERSITY

In general, the BER tracked the path loss. A good example is 6 October from 0000 to 2400. During this period, the path loss increased and then decreased by about 15 dB, the MDS decreased and then increased by 85 nanoseconds, and the BER changed by three orders of magnitude.

The advantage of the implicit diversity, discussed in appendix A, is shown on 2 October from 1800 to 2200, and again on 14 October at 2215 to 16 October at 1220. During the first period, the mission rate was reduced to 256 kb/s (see table B.1), and a BER of 10^{-4} to 10^{-3} was maintained in spite of very high path losses. During the second period, only one receiver was used to measure BER, that is, no explicit diversity. During this time, the BER varied between 5×10^{-4} and 10^{-2}. In dual diversity before this period, the BER was 10^{-7} to 10^{-5} and after this period it was 10^{-6} to 10^{-4}. There were no significant changes in the other parameter during this time. For a single Rayleigh fading channel, the expected degradation in performance (from dual diversity) is about 13 dB, which should have made the link unusable. The BER remained usable because of the inherent diversity in a wide bandwidth digital adaptive system.

B.5 HIGH WINDS AND FADE RATES

The high fade rates starting on 29 September at 0800 and continuing for 3 days (see table B.3) were associated with very high, gusty winds and precipitation. On 30 September at about 0830, antenna 2 at the Vik site moved due to winds of 75 to 90 mph. The period on 2 October from 0400 to 0900 was associated with a frontal passage and accompanying snow. By 1000, it was cool, clear, and calm. On 8 October at 0200, antenna 2 at the Keflavik site moved due to strong gusty winds. Similar correlation between the weather and the fade rates are also seen in week 4. The high fade rates observed during this test were as high and as extended in time as any seen on the other test links. Presumably, the crosswinds in the common volume were also high.

B.6 GENERAL OBSERVATIONS

Most of the week 4 data is unusual. From run to run, the path loss, multipath delay spread, peak-to-peak fading, and fade rates varied in an oscillating and choppy manner. The reason for this is unknown but is assumed to be weather related.

The multipath delay spread curve indicates that all receive paths had the same size common volume, i.e., little difference was seen in the MDS values between receivers. While desirable, other links tested (link engineering project) have shown different size common volumes. Different size common volumes are believed to be caused by antenna foreground effects.

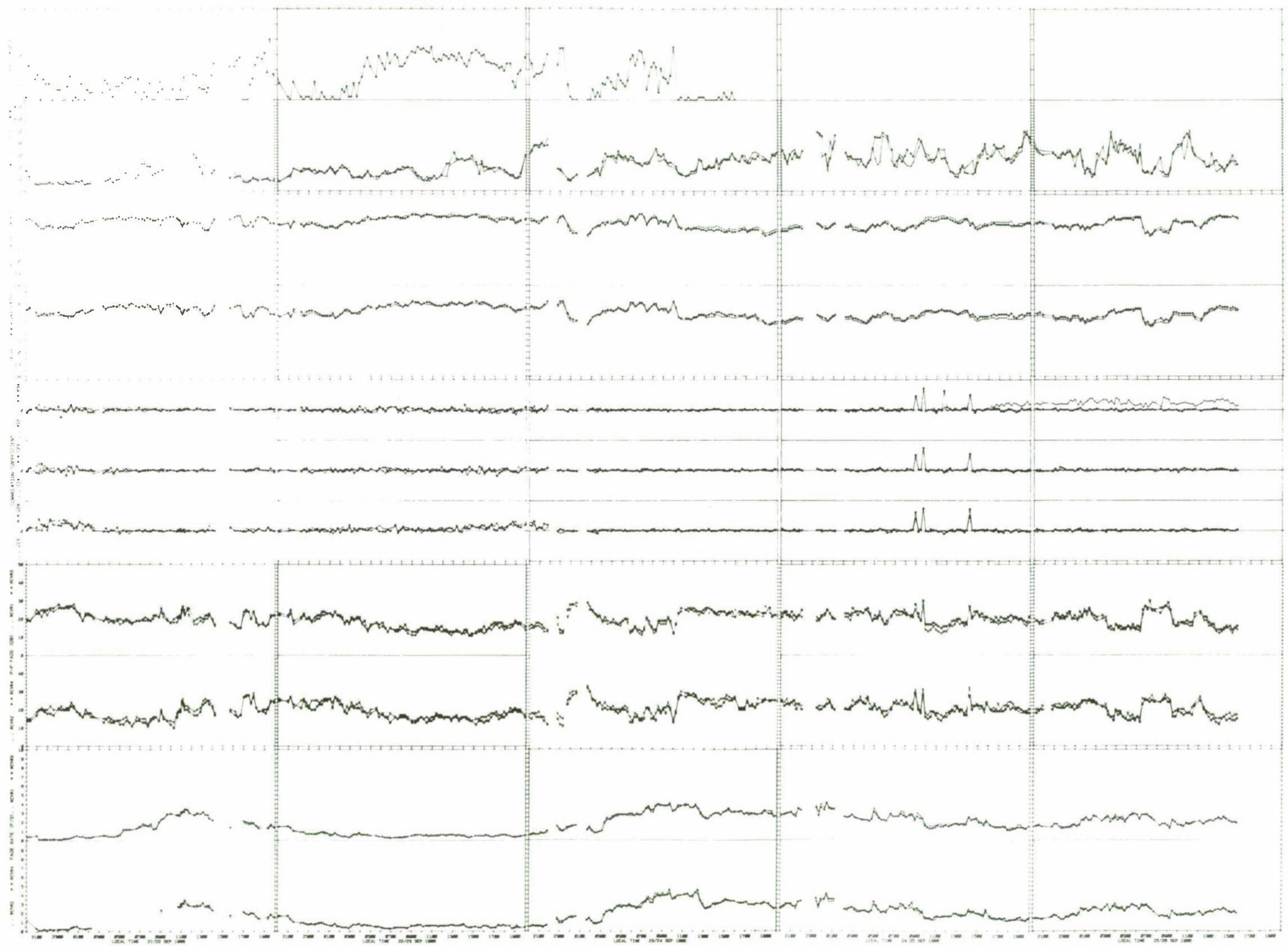


Figure B-1. Detailed Iceland Data for Week 1

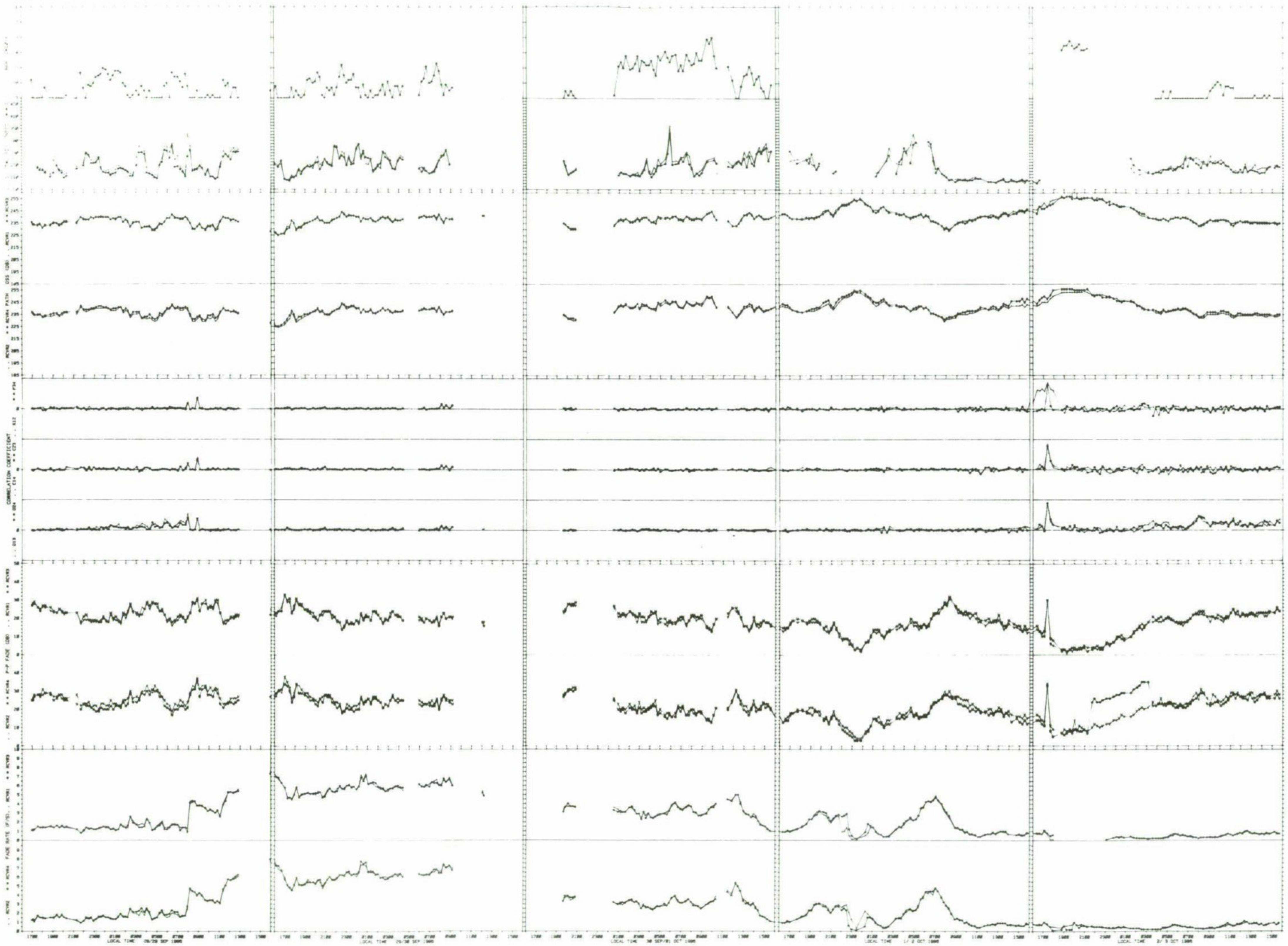


Figure B-2. Detailed Iceland Data for Week 2

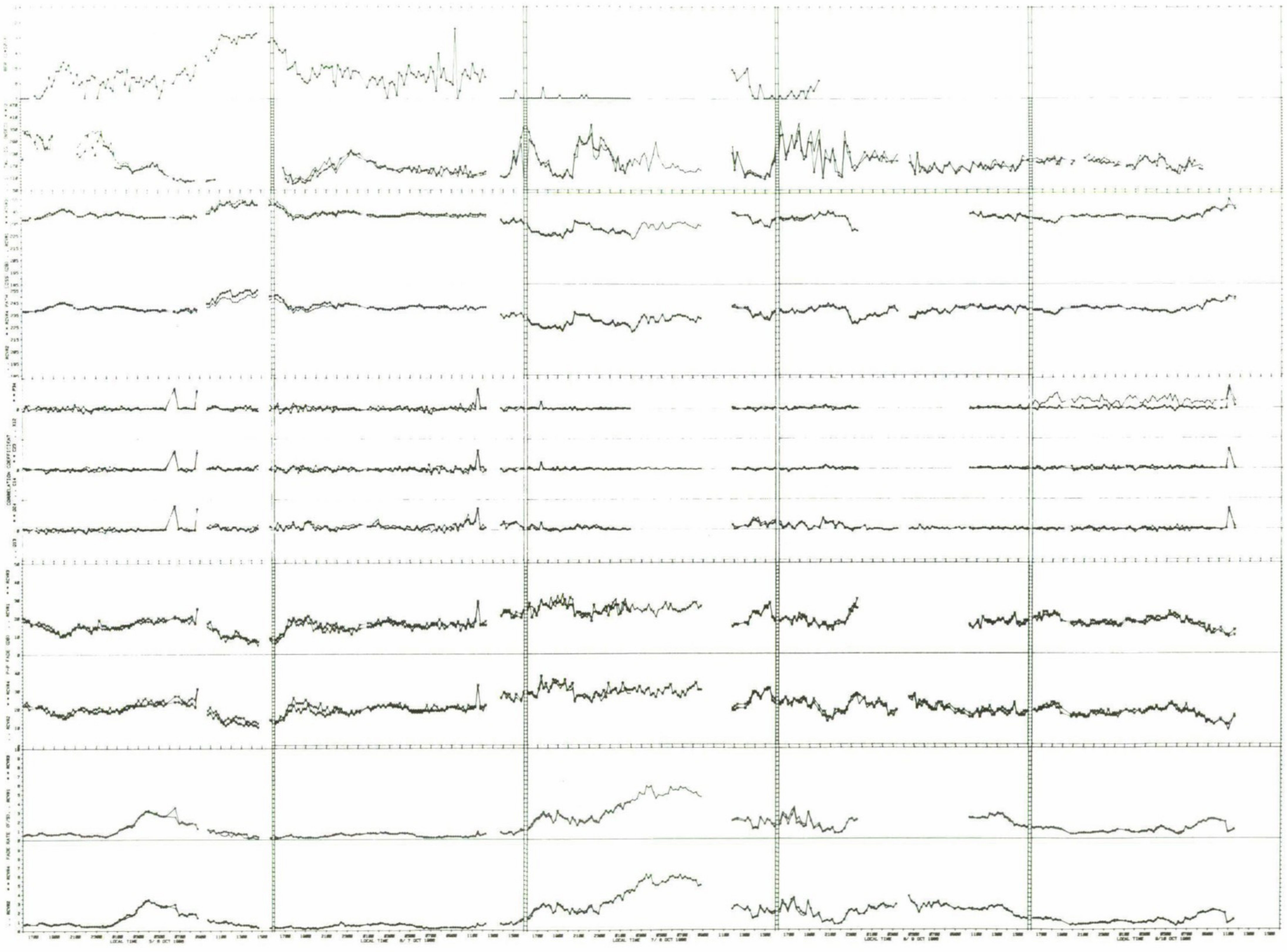


Figure B-3. Detailed Iceland Data for Week 3

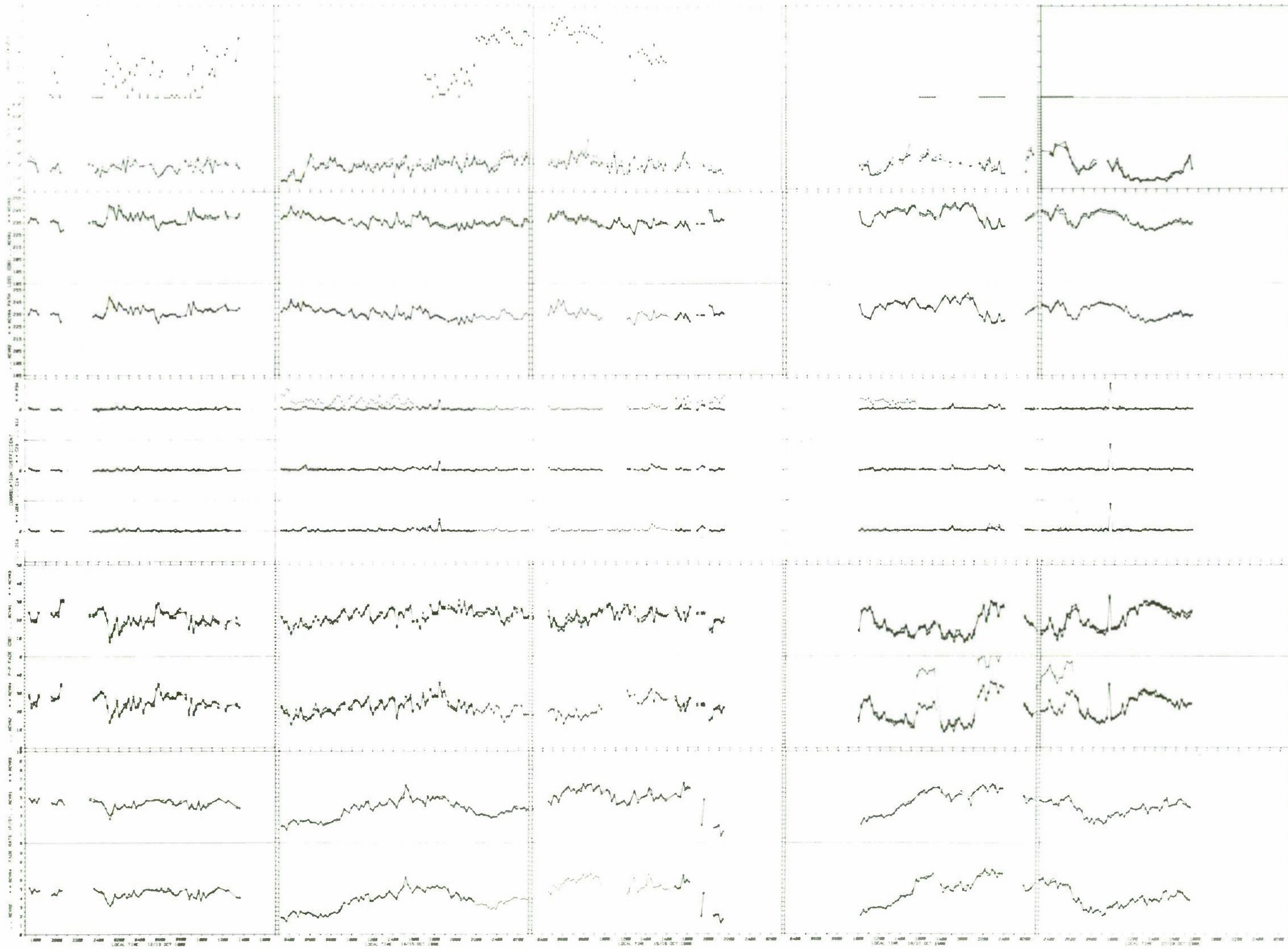


Figure B-4. Detailed Iceland Data for Week 4

GLOSSARY

AEMS	Automated Experiment Measurement System
BER	bit error rate
C-band	3.9 to 6.2 GHz frequency band
CW	continuous wave
DSVT	Digital Subscriber Voice Terminal
DT&E	Development Test and Evaluation
ESD	Electronic Systems Division, Hanscom AFB, MA
FDM	frequency division multiplex
FM	frequency modulator
FSK	frequency shift keying
IADS	Iceland Air Defense System
IF	intermediate frequency
IOT&E	Initial Operational Test and Evaluation
ISI	intersymbol interference
L-band	390 to 1550 MHz frequency band
MDS	multipath delay spread
QPSK	quadrature phase-shift keying
RAKE	a multipath delay spread measurement system
RMS	root mean square
RSL	received signal level
SAT	Site Analysis Tools
"TROPO"	Signatron troposcatter prediction program
USAF	United States Air Force